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Report 1554-TR

EMERGENCY PERSONNEL SHELTERS (U)

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Project 8-07-10-420

17 November 1958

U S Army Engineer Research And Development Laboratories

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U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va - EMERGENCY PERSONNEL SHELTERS (U) - E. P. Leland

Report 1558-TR, 17 Nov 58, 125 pp, [illegible] illus, [illegible] tables
DA Proj 8-07-10-[illegible] Confidential Report

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U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
CORPS OF ENGINEERS

Report 1554-TR

EMERGENCY PERSONNEL SHELTERS (U)

Project 8-07-10-420

17 November 1958

Distributed by

The Director
U. S. Army Engineer Research and Development Laboratories
Corps of Engineers

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PREFACE

The authority for this investigation is contained in Project 8-07-10-420 (formerly 8-07-06-105 and 8-07-06-005), "Field Fortifications and Obstacles," and in a letter, ENGNF, Chief of Engineers to Commanding Officer, Engineer Research and Development Laboratories, 22 April 1955, subject, "Integration of Navy Project NY 340 032 - AW Protective Shelters." Copies of the project card and letter are included as Appendix A to this report.

This investigation was conducted by E. P. Leland, Project Engineer, under the supervision of R. M. Flynn, Chief, Fortifications Section, Demolitions and Fortifications Branch.

A glossary of terms relating to the subject matter is included on page 103.

CONTENTS

SUMMARY

This report covers an investigation into the design of emergency, i. e., improvised or hasty-type, personnel shelters. Existing data were compiled, and the current state of emergency shelter design was analyzed with particular emphasis on protection against nuclear weapons. This investigation was initiated to develop data covering a field in which there was a definite lack of information. It was partially funded by the U. S. Navy Bureau of Yards and Docks which desired information in the field of emergency shelters.

The data incorporated into the report were extracted, paraphrased, or condensed from reviewed publications or were obtained from current research into the subject of field fortifications. The field of investigation was broken down as follows: weapons effects, shelter design components, and types of shelters.

This report concludes that:

a. Weapons effects data are available in sufficient detail for general design purposes subject to the limitations set forth in the following conclusions.

b. Acceptable limits for exposure of personnel to the various weapons effects remain to be established.

c. The design of cover support or framework is not a precise process because of insufficient data on the effect of earth cover on blast forces and insufficient data on the design of structures against dynamic loads.

d. The design of revetment is not a precise process because of insufficient data on the transmission of shock waves through soil.

e. Shelter entrances are quite vulnerable and therefore important. Their design merits careful attention.

f. There is a need for additional data on minimum essential ventilation required for shelters where extended stay times are involved.

g. Optimum protection is obtained when the shelter is placed wholly below the ground surface..

h. The attenuation of nuclear radiation, except for neutrons, is sufficiently understood for design purposes. Additional data are necessary before attenuation of neutrons can be accurately computed.

i. The design of shelters for fallout protection presents no problems except for the aforementioned need for additional ventilation data.

j. The covered-trench shelter is the optimum type of shelter when costs, construction time, and protection are considered, if soil conditions are not prohibitive.

k. When special shelter designs are necessary because of weapons effects or soil condition, the wholly or partially buried shelters are preferred.

EMERGENCY PERSONNEL SHELTERS (U)

I. INTRODUCTION

1. Subject. This is the final report covering an investigation into the design of emergency personnel shelters. Existing literature pertaining to emergency shelters and weapons effects was reviewed, information on design and performance was compiled, and the current state of emergency shelter design with particular emphasis on protection against nuclear weapons was analyzed.

2. Background and Previous Investigation. This investigation was initiated as a result of a conference at Office Chief of Engineers between representatives of OCE, U. S. Army Engineer Research and Development Laboratories, and U. S. Navy Bureau of Yards and Docks. BuDocks desired that USAERDL collate information on emergency personnel shelters. Future planning at USAERDL included an investigation into improvised personnel shelter design. It was decided that Demolitions and Fortifications Branch of USAERDL would begin a project on emergency shelters which would be partially funded by the BuDocks of the Navy. A description of this conference along with a request for a project plan is contained in a letter, ENGNF, OCE to ERDL, 22 December 1954, subject, "Emergency Shelters -- Suggested Joint Army-Navy Action." The proposed plan of the project is contained in a 1st Indorsement, TECRD MO, ERDL to OCE, 17 January 1955, same subject. Copies of the letter and indorsement appear in Appendix B.

Two semi-annual reports were submitted previously. These consisted of preliminary data on weapons effects and design criteria to be considered and bibliographies of all reviewed publications.

II. INVESTIGATION

3. Procedure. During the investigation, publications were reviewed and extracts of pertinent material were made. The publications reviewed were obtained from the Technical Reference Library and the Technical Documents Center of USAERDL and The Engineer School Library. Through the foregoing sources, publications were also obtained from the Library of Congress and the Armed Services Technical Information Agency.

The data incorporated into this section of the report have been extracted, paraphrased, or condensed from the reviewed publications. In addition, data available from research currently being conducted on field fortifications have been incorporated into

the report. Many of the publications were classified for security purposes. To facilitate dissemination of the information contained herein, security classifications in the report are identified by individual paragraphs. Abbreviations designating the particular security classification are placed at the beginning and end of each paragraph containing classified information. A bibliography of publications reviewed and considered pertinent to this investigation is included at the end of the report (page 95). Specific sources of information incorporated into this report are cited by a numbered reference which refers to the corresponding number in a list of references also included at the end of the report (page 91). References are listed in numerical order according to the order in which the reference is first cited. Statements made in referenced paragraphs are the opinions and conclusions of the author of the referenced document and are not to be construed as being necessarily those of the author of this report.

4. Weapons Effects. At the present time, there are four weapons against which a shelter should protect. These are high explosive (H. E.), nuclear, chemical, and biological weapons. These weapons have many individual effects which must be handled separately in shelter design. The individual effects of each weapon will be considered in the succeeding paragraphs.

a. H. E. Weapons. The effects of H. E. shells and bombs can be separated into two components as follows:

(1) Blast. Blast is the major effect of an H. E. explosion. On detonation, the explosive charge of a shell or bomb is converted into a gas of very high pressure and temperature. The shock front formed by expansion of the gas propagates with a velocity which is initially much higher than that of sound; after a distance, the velocity decreases rapidly toward sound velocity as the pressure becomes smaller. This loss in velocity is generally much more rapid than the slowing down of the bomb fragments; therefore, the shock front follows behind the movement of fragments. The blast wave initially consists of two phases, positive and negative. The positive phase of high pressure and short duration is immediately followed by the negative or "suction" phase of less intensity and longer duration (1).

Previous experience in the design of shelters, except for structures of strategic importance, has indicated that it is both unnecessary and uneconomical to provide bomb-resistant protection. The protection necessary was considered to be defense against blast and fragments of a bomb of specified size detonating at a nominal distance. An economical degree of protection has been established on the basis of a 500-lb,

GP (general purpose) bomb detonating at a distance of 25 ft (1).

(2) Fragmentation. Fragmentation of the bomb or shell case causes thousands of sharp-edged fragments to be projected radially in all directions from the detonation at velocities of from 4000 to 7000 ft per second. These fragments will cause considerable structural damage in the immediate vicinity of the explosion and can cause fatalities up to several hundred yards. Maximum fragmentation results from bombs detonating in air; fragmentation is much reduced for bombs detonating a few feet underground. Air resistance to irregular shapes of fragments causes velocity of the fragments to decrease rapidly as distance increases (1).

In many cases, the type and strategic importance of a structure, its small size, or its distance from a larger or more important structure make it both unnecessary and uneconomical to provide bomb-resistant protection for the personnel in the structure. In such cases, consideration is only given to the lateral and overhead protection of personnel, equipment, and structural elements against blast and splinters of a bomb of specified size detonating at a nominal distance from a protective structure. An economical degree of protection has in the past been generally established on the basis of a 500-lb, GP bomb detonating at a distance of 25 ft. The thicknesses of material resulting from this criterion permit good construction practice and maximum structural stability with minimum materials (1).

b. Nuclear Weapons. The major problems in the design of improvised shelters stem from the effects of atomic or nuclear weapons. These effects are considered individually in the succeeding paragraphs.

(1) Blast. An atomic explosion attains very high temperatures causing complete vaporization of the products of explosion. Very hot gases are initially formed at very high pressures. Reduction of these high pressures is attained by expansion of the hot gases which initiates a pressure wave in the surrounding medium. This pressure wave is the so-called blast or shock wave. One important characteristic of this blast wave is the shock front. The shock front is formed by successive pressure waves following the initial one. The successive waves move through a region of higher temperature, and since velocity of the wave increases with temperature, they eventually catch up with the initial wave and form the shock front. The shock wave is the principal cause of property damage. The essential features of a shock wave are an abrupt rise

of pressure, followed by a gradually decreasing pressure, and then a suction phase characterized by a decrease of pressure below atmospheric. Another important characteristic of blast waves is wind drag. The blast wave from an atomic explosion is accompanied by an intense wind that blows throughout the positive and negative phases, reversing its direction at the start of the negative phase. In the case of blast waves of long duration, these winds produce a force on the structure for a relatively long time after the shock front has passed.

From observations made with conventional H. E. bombs, it appeared that peak overpressures of about 200 to 300 psi would be necessary to cause death in human beings by the direct effect of blast and that perhaps 8 psi would produce injury. However, these conclusions do not apply to the situation accompanying a nuclear explosion. In addition to the peak blast overpressure, the rate of rise of pressure and the duration of the positive phase have important influence (2).

The air blast overpressure required to cause rupture of eardrums appears to be highly dependent on circumstances. Several observations indicate the minimum overpressure is in the range from 10 to 15 psi, but both lower and higher values have been reported (2).

Peak overpressures of various intensities as related to distance from ground zero below a typical air burst for various size nuclear weapons are given in Table I.

Table I. Distances from Ground Zero (Miles) for Various Peak Overpressures (2)

	Peak Overpressure (psi)						
Weapon	10	15	20	25	30	40*	50*
1 KT	0.235	0.142	0.098	0.072	0.056	0.036	0.026
10 KT	0.507	0.308	0.212	0.155	0.121	0.080	0.058
25 KT	0.686	0.416	0.286	0.210	0.164	0.108	0.079
50 KT	0.865	0.524	0.354	0.265	0.206	0.136	0.099
100 KT	1.09	0.66	0.454	0.334	0.2360	0.172	0.125
1 MT	2.35	1.42	0.97	0.72	0.56	0.36	0.26
10 MT	5.07	3.08	2.12	1.55	1.21	0.80	0.58
100 MT	10.90	6.60	4.54	3.34	2.60	1.72	1.25

NOTE: These are typical air bursts.

* These distances are extrapolated.

Drag (or wind) pressure can cause translation of the body as a whole. The resulting injury will depend on many circumstances; the most obvious of these are the speed at which the body moves, its acceleration and deceleration, the object it strikes, and the part of the body receiving impact. The translational force, which determines the rate of movement, will be greatly influenced by the frontal surface of the body exposed to the blast wind. A person lying in a prone position will, for example, be much less affected than a person standing up (2).

Drag force is generally dependent on the peak value of dynamic pressure and its duration. Some indication of the corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities in air at sea level are given in Table II. Dynamic pressure is seen to decrease more rapidly than does overpressure (2).

Table II. Overpressure, Dynamic Pressure, and Wind Velocity in Air at Sea Level

Peak Overpressure psi	Peak Dynamic Pressure psi	Maximum Wind Velocity mph
72	80	1170
50	40	940
30	16	670
20	8	470
10	2	290
5	0.7	160
2	0.1	70

Duration of blast waves from nuclear weapons in the megaton range will be several seconds. It is possible that drag forces from megaton weapons may cause damage in excess of that which would be caused by comparable overpressures from small yield weapons; e. g., a drag-type structure may be equally damaged by a 20-MT weapon at an overpressure level approximately 50 percent of that of a 20-KT weapon (3).

Personnel can be injured in two ways by blast, directly or indirectly. Direct injury is due to the characteristics of the wave itself acting on the human body. Indirect injury is due to foreign objects encountering the body. Design of a personnel shelter against blast presents two problems, providing sufficient strength in the shelter to prevent collapse and preventing the entrance of a blast wave of sufficient intensity to cause injury to personnel.

(C) Allowable blast pressures within shelters depend on the characteristics of the blast wave. These include such items as peak overpressure, duration of positive phase, and rate of pressure rise. Experience previous to the atomic bomb indicated that the human body was capable of withstanding over 200 psi of static overpressure without fatality; however, durations were not considered. Tests conducted on dogs showed a fatality pressure of 216 psi for 1.6 milliseconds of static overpressure duration, but for 11.8 milliseconds, the fatal pressure was only 76 psi. After the first atomic explosion, one source (4) suggested a fatal overpressure of 35 psi for humans. Further tests have indicated that this figure could be considerably lower (5). The same source mentions the problem of reflection within the shelter proper which gives an effect of multiple pulses of the blast pressure wave with an increased total duration. Within the shelter proper, another problem to be considered is the effects of winds that possess a translational force and are capable of causing indirect damage. Body damage is not only related to pressure characteristics but also to the geometry of the shelter (5). (C)

(C) As previously pointed out, the rate of pressure rise is one of the significant parameters. Table III sets forth a tentative statement of conditions for step-wise pressure loadings within shelters (5). (C)

Table III. Step-Wise Pressure Loadings within a Shelter (Tentative) (C)

	Maximal Incremental Pressure Rise (psi)	Average Rate of Rise of Incremental Pressure (psi/msec)
Safe	<5	<0.30
Questionable	5-10	0.30 - 0.50
Damaging	>10	>0.50

The above table ignores the maximum pressure and the time between successive pulses. This same source (5) brings out four items to be considered in the design of open shelters against blast. These are (a) pressure differential applied and how this varies with time, (b) air-metering characteristics of the entry system, (c) internal volume of the shelter, and (d) acoustic characteristics of the interior of the shelter. The entry way controls, by throttling, the rate of filling of the shelter. Other things being constant, the larger the shelter volume and the more restricted the entry way, the lower and slower will be

the incremental rises in internal pressure. Acoustic properties of the shelter will affect quality of the reflections from the interior surfaces (5). (C)

Generally speaking, there are two types of military structures. These are the diffraction-type and drag-type. The diffraction-type is a structure which is almost completely closed with a blast-resistant covering. The drag-type is a structure which is essentially open or which has light, non-blast-resistant covering. There are structures that fall between these two extremes, e. g., ones that are partially open or have partially resistant covering. A vehicle and a steel bridge are examples of drag-type structures while a windowless warehouse is an example of a diffraction-type structure. A building with openings greater than 50 percent of the wall area is considered to be a drag-type building, while a building with openings less than 5 percent of the wall area is a diffraction-type building. A personnel shelter, blast entry being undesirable, should be a diffraction-type structure. Since blast enters a drag-type building, it is subject to wind drag and is greatly affected by duration of the blast wave. For a diffraction-type building, the critical blast factor is peak overpressure (6).

(2) Thermal. An atomic explosion attains very high temperatures, emitting a large amount of thermal energy capable of burning personnel and combustible materials. Thermal rays have a long effective range and are emitted very fast. Protection against them is not difficult because they travel in straight lines. The unit of measurement of thermal radiation is the total energy in calories delivered to an area of 1 square centimeter. The primary defense against thermal rays is avoidance of direct exposure of personnel or combustible material. Penetration of thermal rays is very low; for this reason, protective layers can be quite thin (4).

The lethal minimum amount of thermal radiation is not defined exactly. One source (4) gives a moderate-burn intensity of 3 cal/cm^2 and a slight burn intensity of 2 cal/cm^2. Another source (7) gives three ranges of thermal intensity as follows: severe damage, 10 cal/cm^2; moderate damage, 5 cal/cm^2; light damage, 2 cal/cm^2. The preceding degrees of damage refer to troops in the open. A third source (8) gives damage intensities as follows: 2-3 cal/cm^2 for first-degree burns, 3-4 cal/cm^2 for second-degree burns, 8-10 cal/cm^2 for third-degree burns.

At one time, it was thought the amount of thermal radiation received per unit area of exposed material at a specified distance from a nuclear explosion depended markedly

on atmospheric visibility. It appears that within wide limits, however, such is not the case. The reason for this - at first unexpected - effect is that the thermal radiation received at a given point at a distance from a nuclear explosion is made up of both straight-line (unscattered) and scattered radiation. If the air is clear, the radiation received is essentially only that which has been transmitted directly from the exploding bomb without scattering. If the air is lightly hazy, the amount of radiation transmitted directly will be less than in a clear atmosphere. However, this decrease is largely compensated by an increase in scattered radiation. It should be noted that this general conclusion will apply only if the atmosphere is reasonably clear, i. e., in the absence of rain, fog, or dense industrial haze (2).

A shield which merely intervenes between a given target and the ball of fire but does not surround the target may not be entirely effective under hazy atmospheric conditions. A large proportion of the thermal radiation received, especially at considerable distances from the explosion, has undergone scattering and will arrive from all directions, not merely from the point of burst. This situation should be borne in mind in connection with the problem of thermal radiation shielding (2).

Burns, irrespective of their cause, are generally classified according to their severity in terms of the degree (or depth) of the injury. In first-degree burns, of which moderate sunburn is an example, there is only redness of the skin. Second-degree burns are deeper and more severe and are characterized by the formation of blisters. In third-degree burns, the full thickness of the skin is destroyed (2).

The thermal energy necessary to cause burns of various types varies with the total energy yield. A comparison of necessary energies is contained in Table IV (2).

Table IV. Approximate Thermal Energies Required to Cause Skin Burns in Air or Surface Burst (2)

Total Energy Yield	Thermal Energy (cal/sq cm)		
	First Degree	Second Degree	Third Degree
1 KT	2	4	6
100 KT	2½	5½	8
10 MT	3½	7	11

Thermal energies of various intensities, as related to distance from explosion for various size nuclear weapons are given in Table V.

Table V. Slant Range (Miles) from Explosion for Various Bomb and Thermal Energies (2)

Weapon	Thermal Energies (cal/sq cm)								
	2	4	6	10	25	50	100	1000	10,000
1 KT	0.68	0.51	0.42	0.33	0.23	0.16	0.11	0.03	-
10 KT	1.90	1.47	1.20	0.93	0.60	0.45	0.33	0.11	0.03
25 KT	3.0	2.1	1.7	1.45	0.93	0.68	0.51	0.17	0.05
50 KT	4.1	3.0	2.6	1.9	1.3	0.93	0.68	0.24	0.07
100 KT	5.6	4.1	3.4	2.7	1.7	1.3	0.93	0.33	0.11
1 MT	16.5	11.5	9.7	7.6	5.0	3.6	2.7	0.93	0.33
10 MT	-	-	30	23	14	11	7.6	2.7	0.93
100 MT	-	-	-	-	-	-	23	7.6	2.7

NOTE: Visibility of 2 to 50 miles air burst.

Protection against thermal radiation requires non-direct exposure; however, thermal rays can be reflected and still cause damage. The quantity reflected depends on the reflecting material.

It has been estimated that reflection as high as 10 to 15 percent is possible (9). On that basis, generally, two reflections are considered sufficient to reduce the thermal rays to a negligible quantity (10). A British source (11) reports negligible reflection of thermal rays by soil. Reflection of thermal rays by Nevada sand has been reported as low; moreover, it is considered possible that the small amount of thermal energy measured was not reflected thermal radiation but instead was heated air (12).

During a test on a Federal Civil Defense Administration (FCDA) shelter located at close range, peculiar thermal effects were reported. The shelter possessed an entrance containing two right-angle turns, but thermal effects were observed within the shelter proper. The fur of experimental animals placed in the shelter was singed. Animals in cages which were barely larger than the animals themselves were singed possibly because the fur projected between the bars of the cages. Other animals in larger cages were not singed when there was no fur projection between the bars. It was believed that the singeing was caused by heated air. Cooling of the heated air

by contact with the bars of the cages was the explanation for the non-singeing of fur in the larger cages. This indicates that even though thermal radiation may be reduced to a negligible quantity by successive reflections, personnel may be injured by heated air in open shelters (13).

(3) Gamma Rays. Gamma rays are one of the major emissions of nuclear weapons. The energy of gamma rays from an atomic bomb varies. Attenuation of gamma rays varies with their energy. The average energy of gamma rays from a 20-KT bomb at distances greater than 3,000 ft is about 3 Mev (4).

The average energy of gamma radiation from a nuclear explosion is 4.5 Mev. The effects of varying intensities of acute radiation doses are contained in Table VI (2).

Table VI. Effects of Prompt Whole-Body Gamma Radiation Doses (2)

Prompt Dose (r)	Probable Effect
0 to 50	No obvious effect, except possible minor blood changes.
50 to 375	Some sickness in personnel, varying from 1 percent for 50r to 100 percent for 375r.
200 to 750	Some deaths in personnel, varying from 1 percent for 200r to 100 percent for 750r.
225	Fifty percent of personnel are sick.
450	Fifty percent of personnel die.

NOTE: Prompt doses are delivered in a matter of minutes as distinguished from fallout which may be delivered over several days.

Gamma rays are attenuated with depth into materials. The amount of attenuation varies approximately with material density. Materials such as earth, concrete, and metal are very effective in attenuating gamma rays.

The delivery time of immediate gamma radiation in the range of a 20-KT weapon is very short. Since 50 percent of the dose is delivered within the first 0.5 second and 90 percent within the first second, there is very little time for

personnel to seek shelter from gamma radiation immediately after the explosion.

The delivery time of immediate gamma radiation in the megaton range of atomic weapons is considerably longer. A 5-MT weapon delivers 50 percent of the dose within the first 5 seconds and 90 percent within the first 10 seconds (2).

Seeking protection against gamma rays after the explosion of this size weapon is a distinct possibility. Gamma radiation is a very important effect of weapons in the kiloton range; however, recent data indicate that gamma rays from a megaton weapon are a problem only where blast pressures and thermal energies are already very high.

Gamma radiation of various intensities, as related to distance from explosion for various size nuclear weapons are given in Table VII.

Table VII. Slant Range (Miles) from Explosion for Various Bomb Yields and Gamma Ray Doses (2)

Weapon	Gamma Ray Doses (r)					
	100	300	1000	3000	10,000	100,000
1 KT	0.54	0.42	0.32	0.23	0.15	0.08
10 KT	0.83	0.70	0.55	0.43	0.33	0.16
25 KT	0.95	0.80	0.65	0.52	0.40	0.22
50 KT	1.06	0.92	0.76	0.62	0.49	0.28
100 KT	1.22	1.05	0.88	0.74	0.59	0.35
1 MT	1.77	1.57	1.38	1.24	1.05	0.74
10 MT	2.55	2.28	2.00	1.80	1.60	1.23

(4) Neutrons. Neutrons are one of the major emissions of atomic weapons. They are measured over various energy regions. The unit of measurement is the number of neutrons per square centimeter. According to one source (4), the energy range of neutrons can be broken down into three fields for measurement. The first of these, the so-called "fast" neutrons, have energies in excess of 3 Mev. The energy range of the so-called "slow" neutrons is somewhat uncertain, but it is probable that it is around 0.2 ev. The energy range of the intermediate range group is from about 0.2 ev to 3 Mev (4).

The accepted unit of measurement of the intensity of neutrons is the "roentgen equivalent mammal" or rem. One rem of neutrons is equivalent in biological effect to one

roentgen of gamma radiation. Therefore, the intensity of neutrons for shelter design purposes is measured in rems. Neutron radiation of various intensities, as related to distance from explosion for various size nuclear weapons are given in Table VIII (2). Comparison of this table with Table VII shows that for weapons of 10 KT or less, the neutron intensity is greater than the gamma intensity and at distances where there are high intensities, the neutron quantity is greater for 100 KT or less.

Table VIII. Slant Range (Miles) from Explosion for Various Bomb Yields and Neutron Doses

Weapon	Neutron Doses (rem)					
	100	300	1000	3000	10,000	100,000
1 KT	0.60	0.50	0.40	0.32	0.225	0.08*
10 KT	0.82	0.71	0.60	0.50	0.40	0.225
25 KT	0.92	0.79	0.69	0.58	0.48	0.29
50 KT	0.99	0.87	0.75	0.65	0.54	0.34
100 KT	1.06	0.94	0.82	0.71	0.60	0.40
1 MT	1.32	1.20	1.06	0.94	0.82	0.60
10 MT	1.60	1.45	1.32	1.20	1.06	0.82

* Estimated distance by extrapolation.

The number of neutrons generally accepted as lethal is 5×10^{11} per square centimeter for slow neutrons and 10^{11} for fast neutrons. Lethality of neutrons varies directly with their energy. For the Hiroshima or nominal bomb (20 KT), there are approximately 10 times as many slow neutrons as fast neutrons. For this reason, even though the fast neutrons are more lethal individually, slow neutrons are the more important hazard. An additional item of difference between slow and fast neutrons relates to scattering. Fast neutrons are essentially directional. Slow neutrons follow erratic courses and, therefore, complicate the design problem regarding openings.

The problem of shielding against neutrons is not easily solved. Water or any other material containing hydrogen is very effective in slowing down neutrons. To increase effectiveness of water, dissolvable borax may be added. Soil may also be made more effective by addition of borax. Concrete, which contains a large amount of hydrogen (in the form of water), is another effective shielding material. These solutions are of little value for emergency shelters, but this problem will be covered further in the section on attenuation factors.

Early data (4) on the effective range of neutrons led to the conclusion that neutrons did not present an additional hazard when protection was provided against other effects. This would not hold true against shelters designed for close-in protection.

(C) Later data (14) states that for a thin shell bomb such as the atomic artillery shell, over the range of biological interest for gamma radiation (200-1000r), the biological effectiveness of neutrons appears to equal that of gamma rays. With a greater attenuation problem for neutrons than for gamma rays, this device may make protection against neutrons the more critical design problem. (C)

Tests in Nevada show that attenuation of neutrons passing through earth was less dependent on the slant thickness than it was on the minimum thickness of earth over the shelter. Chemical composition of cover material is the most significant factor concerning neutron shielding (15).

(5) Alpha Particles. One of the immediate emissions of an atomic explosion is the alpha particle. An alpha particle has a very small effective range, a few inches only, and is dangerous to personnel only when it is inhaled or ingested. As far as immediate effects of an atomic explosion are concerned, the alpha particle is not considered a design problem (4).

(6) Beta Particles. One of the immediate emissions of an atomic explosion is the beta particle. A beta particle has a very short effective range, a few feet only, and is dangerous to personnel only when it is in contact with the skin or when it is inhaled or ingested. As far as immediate effects of an atomic explosion are concerned, the beta particle is not considered a design problem (4). Fallout is another matter; beta particles are significant in connection with fallout.

(7) Fallout. Fallout is the effect of the secondary phase of a nuclear explosion. Radioactive particles from a nuclear explosion are carried aloft by the force of explosion. These particles settle to the ground at such a slow rate normally that most of their radioactivity has dissipated before they fall to earth. However, if the same particles become attached to soil particles drawn up into the radioactive cloud or if radioactivity is induced into the soil particles by neutrons, the phenomenon known as fallout occurs. The contaminated soil particles are considerably heavier than the radioactive particles and settle to the ground more rapidly. These soil particles can be borne great distances by winds and still be

highly radioactive. When they eventually settle, they are still capable of contaminating an area for days, even weeks. This long contamination period requires an extensive shelter duration time plus means of preventing entry of fallout particles into the shelter.

One source (16) of particular interest states that a person standing in an open field, uniformly contaminated with fallout, receives 50 percent of his radiation from the fallout which is over 25 feet away from him. From this statement, it appears that one can obtain greater than 50-percent protection against fallout by getting below the ground surface.

Fallout consists mostly of two effects, gamma rays and beta particles. The gamma ray is the main problem in fallout. The energy of the fallout gamma ray is lower than the energy of the prompt gamma and, therefore, is protected against more easily. The average energy for gamma rays from fallout is 0.7 Mev (17).

The alpha particle is another effect of fallout; however, its properties are similar to the beta particle and are of lesser danger. Protection against beta particles is more than sufficient for protection against alpha particles.

(C) During Operation CASTLE (18, 19), some people were subjected to unexpected gamma and beta fallout. Beta fallout was dangerous only on the skin and when inhaled or ingested. The inhaled amount was small because most of the particles were stopped at the nostrils or in the mouth. However, the amount ingested was of importance because of contaminated particles swallowed directly and because of contaminated food and drink. Exposed skin was damaged by "beta burn" which is a combination of beta particles and low energy, 1 to 100 kev, gamma rays. There was no skin burn under clothing except where the radioactive material was carried by perspiration or body motion under a collar or cuff. Skin burn occurred only when the particles came into direct contact with the skin. The whole body dose of gamma radiation from particles distributed on the ground, trees, and buildings was approximately 200r in this particular instance. It was stated (19) that for well clothed personnel in a fallout field, the gamma dose will be the critical effect in determining the time of entry into, or period of exposure within, such an area. The clothing in this case, even a single layer of cotton, provided almost complete protection against "beta burn." (C)

c. Chemical Warfare Agents. The problem that "gas warfare" presents is not easily solved especially in emergency or

improvised shelters. Complete protection against choking gases, vomiting gases, and some of the blood gases can be obtained through the protective gas mask. However, blister gases, nerve gases, and some blood gases not only require the protective mask but also require protective clothing because they are harmful to skin or are capable of entering the body through the skin and causing fatalities. The only other protection against these gases is a closed shelter with filtered ventilation, preferably with a positive interior pressure. Mechanical ventilation is not considered in the design of these emergency shelters; however, some protection can be provided by sealing entrances and vents. This limited protection will be brought out in the section on entrance design (20).

d. Biological Warfare Agents. The problem that "germ warfare" presents is not easily solved, especially in emergency or improvised shelters. The protection necessary consists of complete sealing of the shelter from any exterior contamination. It would be preferable to have the interior air pressure greater than atmospheric. The limited protection afforded by sealing will be brought out in the section on entrance design (20).

5. Shelter Design Components. The term "emergency shelter" as used throughout this report is defined as a shelter capable of being erected swiftly with commonly available means and materials, i. e., an improvised personnel shelter. The components to be considered in the design of emergency personnel shelters are discussed below.

a. Earth Cover. Earth cover is one of the most readily available, cheapest, and valuable protective materials for shelters.

Damage to structures is less severe when they are covered by even a small amount of earth (21).

The many advantages of setting the top of earth cover at natural grade far outweigh additional costs (22).

In designs of field defenses for an atomic war, vertical faces projecting above ground level should be avoided. If it is impossible to keep everything flush with the ground, then the face of everything above ground level must be sloped off to an angle of less than 35 degrees from horizontal.

The regime of forces applied to the surface of an earth-covered structure is extremely complex, both from point to point over the surface of the structure at any given instant and in the time variation at any given location. Furthermore, the response of even relatively simple structures to complicated loads is a difficult analytical problem. It is thus commonly unprofitable to

attempt a detailed analysis of so complex a problem. There is, therefore, a strong impetus for the use of simplifications which will permit relatively easy (even though approximate) solutions (23).

The parameters which control effectiveness of earth cover in protecting structures against damage produced by the blast from atomic explosions involve properties of the earth cover, properties of the structures, and the inter-relation of the two. The inter-relation is of major importance. The parameters are discussed separately for purposes of logical presentation (24).

In general, earth cover reduces blast damage to a structure in several ways. First, it reduces the forces applied to the structure, both because the shape of the earth cover will ordinarily reduce the forces exerted by blast and because those forces which are applied to the surface of the earth are transmitted in reduced intensity to structure surfaces which are below the earth surface. Second, the earth cover acts to modify and, in general, improve response of the structure to forces applied to it. This improvement in response of the structure is accomplished primarily by buttressing, i. e., resistance of the earth to compression by any parts of the structure which tend to move outward, and secondarily by the increase in mass which resists motion because of its inertia. It should be noted that these properties are functions particularly of the interaction of the earth cover and the structure (24).

The shape of the top surface of the earth cover has a very great effect on the forces applied by air blast and particularly has a major effect on the dissymetry of forces applied to the windward and leeward sides of the earth cover. This is a major parameter affecting the forces applied to a structure. Higher values of elastic moduli, as controlled by choice of earth for the cover and by compaction during the filling operation, have the beneficial effect that buttressing of the structure is improved. Increased moduli will generally also be associated with increased density; this, in turn, will have a minor benefit in adding to the effective mass of the structure. On the negative side is the increased cost of compaction. It is estimated that the cost of placing the earth cover may well be increased by more than a factor of 2 by careful compaction compared to no compaction whatever. Also, in the case of very flexible structures, care must be exercised during compaction to avoid collapse of the structure (24).

When the air blast from an explosion moves over an earth-covered structure, loading of the structure surface due to earth pressure will be less sudden than loading of the earth surface due to air pressure for the following reasons. (1) Since the stress at a point on the shelter surface derives from the loading on a relatively large area of earth surface, the earth pressure rise time is

lengthened because of the time required for the blast wave to move over this area and (2) the rise time of the earth pressure at the structure surface is also lengthened due to the finite velocity of transmission of stress in the earth cover. This lengthening of the rise time is important where either the structure as a whole or a component element of it has a period of response which is less than the resultant rise time of the earth pressure against it. Important benefits from an extension of the rise time exist only if the rise time can be extended beyond the time required for maximum response of the element under a shock load (24).

In the limiting case where there is no deflection of the structure, earth pressure gages in the center section of a structure should show somewhat longer rise times than corresponding air pressure gages, but they should level off at approximately the same value and, thereafter, follow the decreasing air pressure curve. The side section earth pressure gages should show even longer rise times than the center section (due to the greater thickness of earth cover) and rise to a pressure considerably less than the corresponding earth surface pressure. The shape of the curve after the rise should approximate the shape of the decreasing air pressure curve (24)

For the case where the structure deflects, the mechanism becomes complicated. There are three effects associated with earth cover which will affect the force acting on the structure. (a) Acceleration of the earth cover will reduce the force acting on the structure by the force m a_1. Later deceleration of the earth cover will increase the force acting on the structure by the amount m a_2. (b) As the earth cover follows the structure surface, there will be a small flow of earth. The friction associated with this flow will reduce the force acting on the structure. This appears to have only a minor effect on the maximum force acting on the structure (c) Another factor which will affect earth pressure at the structure surface is the transmission of forces between different segments of the structure surface. The earth pressure curves for a deflecting structure are affected by accelerations of the earth cover and the transmission of forces between different segments of the structure surface. Therefore, except for cases where deflections are small, it is to be expected that the loading history of the structure will be complicated and difficult to interpret (24).

Extensive tests have indicated the thickness of various materials required to resist blast and fragments of H. E. bombs. The majority of tests were made on the basis of protection against 500-lb, GP bombs. Protective thicknesses adequate for protection against all types of bombs at a distance of 40 ft are given in Table IX. These thicknesses may be regarded as providing 95-percent protection at 25 ft, provided structural continuity and good quality construction are maintained (1).

Table IX. Required Thicknesses of Materials To Protect against Fragments and Blast of Various Size GP Bombs at a Distance of 40 Ft

Size of Bomb	Thickness in Inches			
	Mild Steel	Concrete Block	Packed Earth	Sandbags
100 lb	1	16	20	24
250 lb	1½	20	24	30
500 lb	2	24	30	36
1000 lb	2½	28	36	42
2000 lb	3	32	42	54

NOTE: These thicknesses are 95 percent effective at a distance of 25 ft.

Tests conducted during Operation Teapot on earth-covered prefabricated ammunition-storage magazines used as personnel shelters resulted in a conclusion that the design of earth-covered structures based on stress analysis was not possible under present conditions and further effort in that direction was not advisable (25).

Propagation of shock waves through soil is a subject of special interest to the designer of shelters. The concept of a wave being transmitted steadily in one direction or spreading out from a point source is an idealized one. In practice, all waves move in bounded media, and wherever boundaries of discontinuity are encountered, reflection and refraction will occur resulting in more or less complex wave patterns. The amount of energy reflected is dependent on the contrast in acoustic impedances (i. e., product of mass density by seismic velocity) of the soils on each side of the boundary at which the reflection takes place. It is independent of the side from which the incident wave approaches. Where there is little difference in the elasticity and density between an overlying and an underlying formation, there is little reflection. Some research has shown that a considerable contrast must exist in acoustic properties in order that reflections of recognizable amplitude be produced at the interface of two distinct media. If there is a sharp difference in elastic and physical properties thereby creating an actual discontinuity, much of the energy will be reflected from the interface. In stratified materials possessing different characteristics, the phenomenon of seismic reflection and refraction will occur. The conditions are usually expressed in the relationship between the radiation resistances or acoustic impedances of two adjacent media since this factor controls the transmission of energy from one medium to another, as well as the ratio of reflected to incident energy. If in two media, the specific acoustic impedances differ greatly, the

energy transmitted from one medium to the other is negligible and almost perfect reflection will occur. To satisfy the conditions for reflection, a definite change in compressibility or in density must be made. Some examples of material with widely varied impedances, compressibilities, and densities are solid rock, gravel, plastic clays, sands, and loams.

The foregoing indicates that if earth cover can be placed in layers of widely varied impedances, it may greatly reduce the transmission of shock waves to the supporting structure. This factor is highly significant for protection against H. E. shock waves of short duration. It has been found effective as a means of protection against conventional artillery attack. It has not been evaluated by experiment with atomic weapons. It is anticipated that pressure-rise time on a structure under atomic attack can be beneficially controlled in this manner, but that it will have little effect on peak pressure. A pressure pulse from an atomic explosion is of such long duration as compared to the natural frequency of vibration for most emergency shelters that it assumes many characteristics of a static load. Hence, peak pressure is the controlling parameter.

The optimum design of an earth-covered shelter is that design which will resist a specified blast load, be functional before and after one exposure to atomic blast, and be of minimum cost consistent with these requirements. The most important parameter affecting cost will be the specified clear span. This should be held to a minimum. For example, enormous capacity could be developed in a culvert section of 6-ft radius under 5 ft of cover. Such a structure might be the most economical. The highest level of protection per dollar will be attained if the span of the arch is kept to the minimum possible to accommodate the appropriate function of the structure. Thickness of earth cover near the crown of the arch should be determined by considerations other than protection against airblast damage, radiation hazard, and missile hazard (24).

b. Cover Support. One of the major problems encountered in the design of emergency shelters is support for the earth cover. The cover support has to carry not only the blast loads but also the static or dead load of the earth cover.

The design of underground protective construction to resist air blast from atomic bombs presents difficulties only where the pressures are extremely high. In general, for low pressures, 20 to 30 psi, the amount of cover required for radiation protection is great enough so that the static strength of the structure required to support the cover under the usual working stresses will generally be sufficient to resist the dynamic forces. Special consideration, however, may have to be given to the effects of very long duration pulses of pressure resulting from the blast of extremely large bombs.

When pressures are extremely high, in the neighborhood of 100 psi, some special consideration is required because the reserve strength required for normal design under static conditions would not be sufficient (26).

One must take into account the nature of collapse of structural elements used in construction. Wherever possible, one should use materials and types of fabrication that permit absorption of energy without brittle failure. Finally, one should take account of the fact that vibrations are likely to occur under dynamic conditions and that reinforcement and anchorage should be provided to resist the full effect of reversal in the elastic range, i. e., a structure designed for downward loading may often be subjected to an upward loading consistent with an elastic vibration just equal to the yield deflection of the structure. If the structure is not so designed, it may suffer secondary collapse which may be serious (26).

The upward pressures exerted on the bottom of buried structures are of the same order of magnitude as the pressures on the roof. A base pressure of about 3/4 the roof pressure appears to be sufficient for design purposes unless the duration is extremely long. This will take into account the absorption of pressure which produces acceleration of the top surface of the structure and of pressure which produces acceleration of the structure as a whole (26).

Design criteria should be selected which correspond to conditions at yielding or at limit behavior of the structure. When collapse loads or limit loads are selected, consideration should be given to the probable actual strength of the material under conditions applying to the structure in practice. For very long pulses, the structure should be designed for the pressures described above, acting as static pressures, for stresses at least 10 percent below those corresponding to general yielding. For structures at or very close to the surface, the design stresses should be at least 20 percent below those corresponding to general yielding (26).

There is little evidence of dynamic arching in the pressures acting on the roof of beam strips, except where the deflection became exceedingly large. The arching begins to be effective after the deflections have reached values corresponding to about 5 percent of the span. This amount of deflection would correspond to failure in ordinary reinforced concrete construction of the thickness that would be required for large pressures. For practical design conditions, it does not seem advisable to count on dynamic arching to reduce the design loads (27).

For flexible structures, the buttressing effect of the earth cover is a benefit of prime importance. "Buttressing effect" is the informal expression used to describe the passive

resistance of the soil to lateral displacement. No earth-covered structure can move to leeward without overcoming this soil resistance, and no arch or gable frame roof can be displaced downward at the crown without overcoming similar soil resistance at each haunch (24).

(C) Tests were conducted on field fortifications during Operation UPSHOT KNOTHOLE. The structures consisted of command posts, machine gun bunkers, and foxholes. The command posts, Fig. 1, and machine gun bunkers, Fig. 2, were typical structures, as in FM 5-15, consisting of posts, caps, and stringers. The posts and caps were 8 by 8 timbers while the stringers were 4 by 4 timbers. The structures were tested by two different shots. The initial shot caused roof collapse in many of the command posts and bunkers. Collapses were due to failure of the center cap which in turn caused failure of the stringers. Failures of the machine gun bunkers were not as numerous as failures of the command posts. The explanation for this difference is that the pressures within the bunkers were

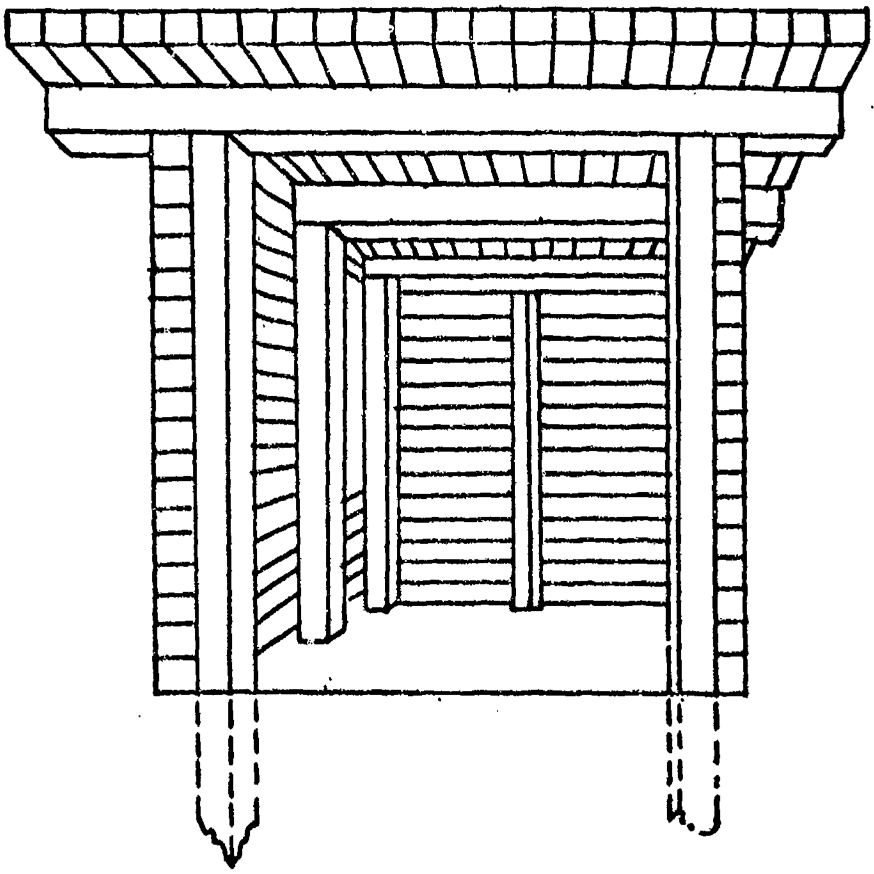


Fig. 1. Command post.

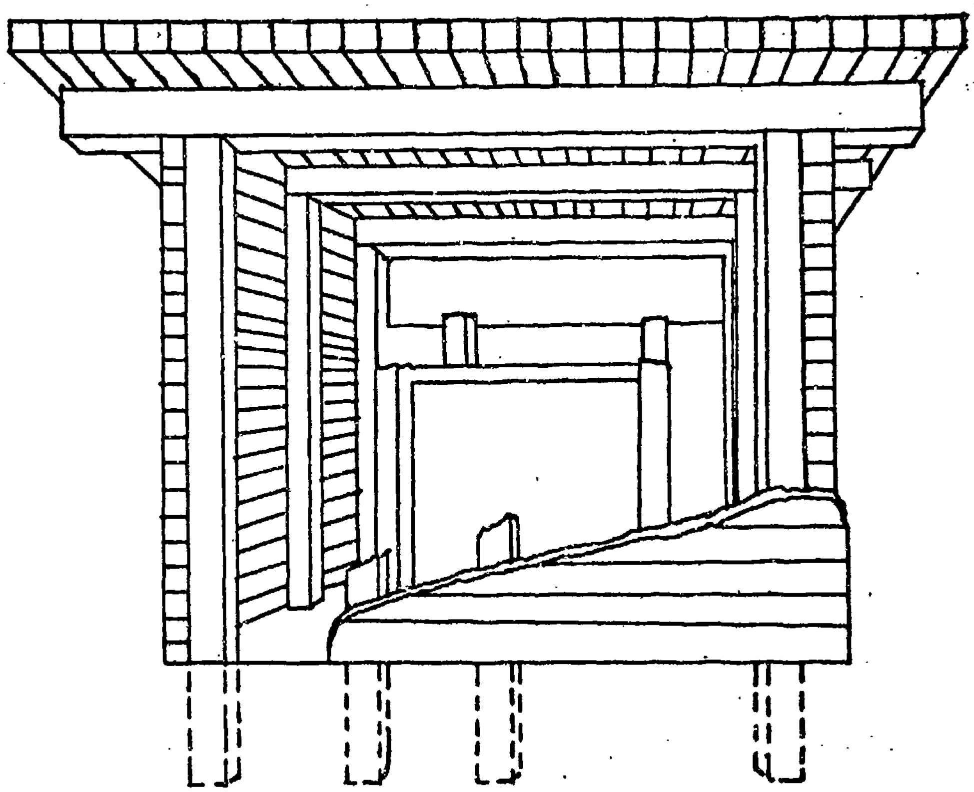


Fig. 2. Machine gun bunker.

twice the pressures within the command post, i. e., the machine gun emplacement cover was subjected to a lighter load because of the relieving pressure inside reaching a significant value in a shorter time. Structural damage to covers of command posts and machine gun emplacements was a result of blast-induced pressure difference between the top and bottom of the cover. The effect of dynamic or wind pressure was much in evidence. For the command posts, damage was limited to removal of part of the loose earth cover; whereas, for machine gun emplacements whose cover structure was above grade level, the effects were multiple. Generally speaking, the dynamic pressures were effective in tearing the cover materials apart from each other where they were joined, blowing away the loose materials, and moving whole covers or parts thereof out of position (10). (C)

(C) The second shot which included a precursory effect was very damaging. Of all parts of the fortifications that had originally been above natural grade level, little or nothing remained in place. The covers to machine gun emplacements could not be identified after the shot. Although the covers to command posts stood up better than the others, none remained intact. It

appeared that the 8 by 8 center caps had failed first in horizontal shear and then in bending at midspan, and that the end caps had failed in horizontal shear only with a beginning failure in either bending or vertical shear. About 1/4 of the 8 by 8 timber posts failed in compression, a few were driven slightly farther into the ground, and most were left leaning inward to some degree (10). (C)

(C) Fortification covers located flush with grade level are primarily damaged by diffraction-type loading. When the covers are located above grade level, cover components may be seriously disarranged by dynamic pressure; however, the physical breaking of timbers and materials themselves is still a result of diffraction loading on the cover. Disarrangement begins to appear at dynamic pressures as low as 0.7 to 1.6 psi and is dependent on the design and the quality of workmanship going into the joints and fastenings. For both above and below grade covered fortifications, the longer spanned, horizontal supporting members limit the strength of the cover's resistance to diffraction loads. The posts supporting these caps are relatively invulnerable to damage from loads on the cover; if the soil is at all stable, they are better sunk into the soil than set on timber footings or spreaders (10). (C)

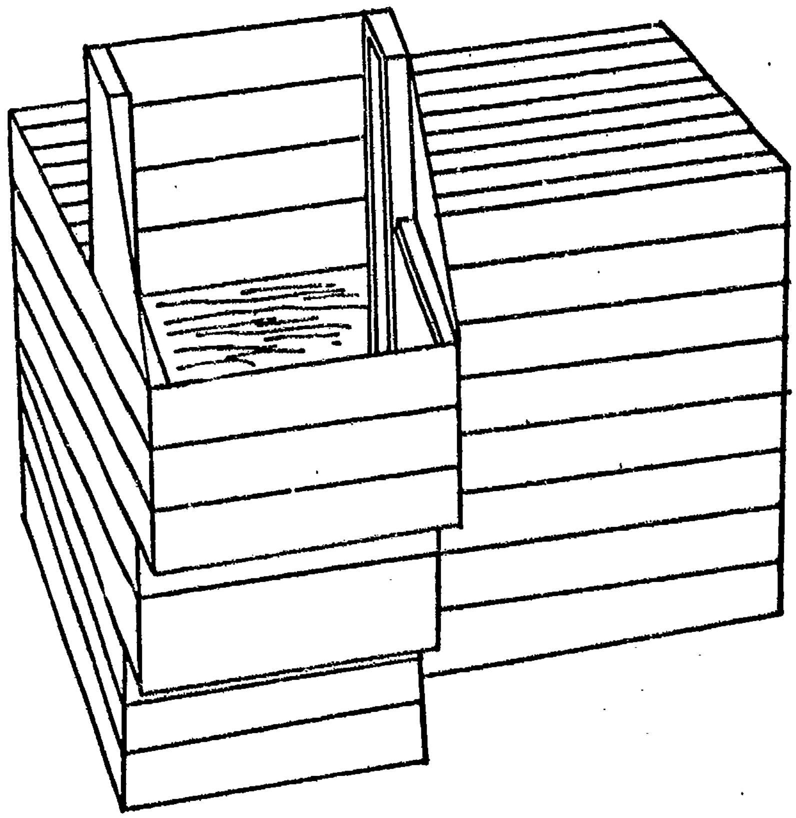


Fig. 3. FCDA family-type shelter.

(C) FCDA family-type shelters were tested during Operation BUSTER. One of these, Fig. 3, was a completely enclosed shelter of wood. It was of small capacity, four persons only, and consisted of 2 by 4 studs and 2 by 6 roof joists with a wall, floor, and roof covering of 1 by 6 sheathing. The joists were spaced at 3-3/4 in. and the studs at 16 in. The roof span was 4 ft. The roof supported 3 ft of earth cover and, in addition, resisted peak pressures of 15 psi (21). (C)

(C) A communal shelter, Fig. 4, consisting of 90-in. inside diameter, 24 ft long, reinforced concrete pipe and 90-in. inside diameter, 10 gauge, 24 ft long, corrugated iron multiplate pipe was tested during Operation BUSTER. The shelter covered with 3 ft of earth withstood 25 psi overpressure (22). (C)

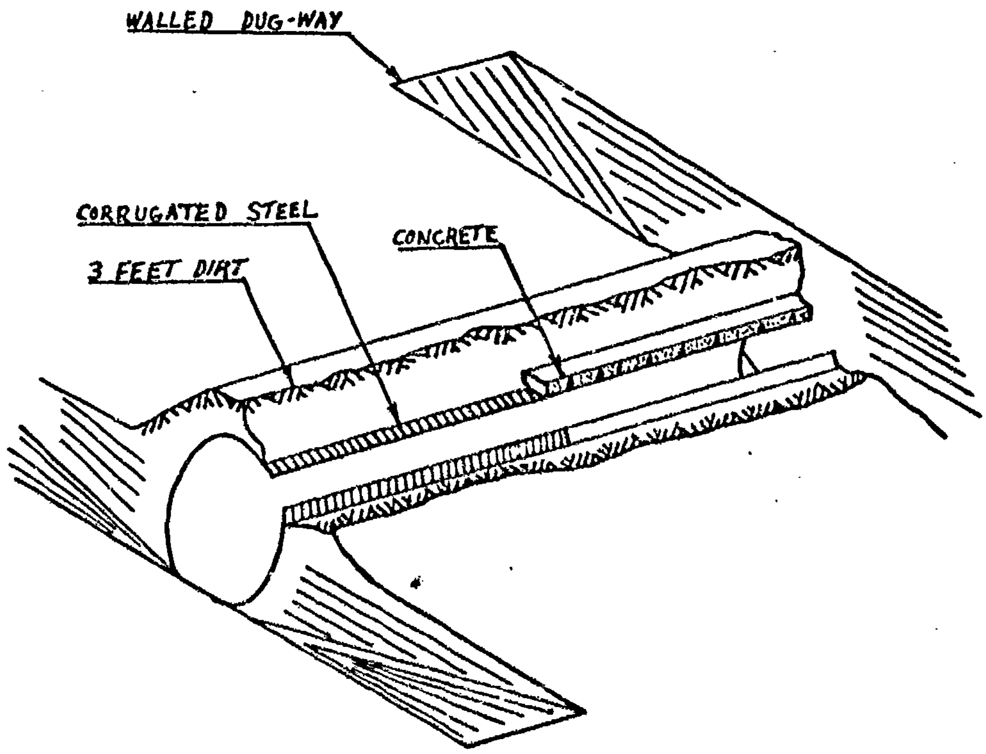
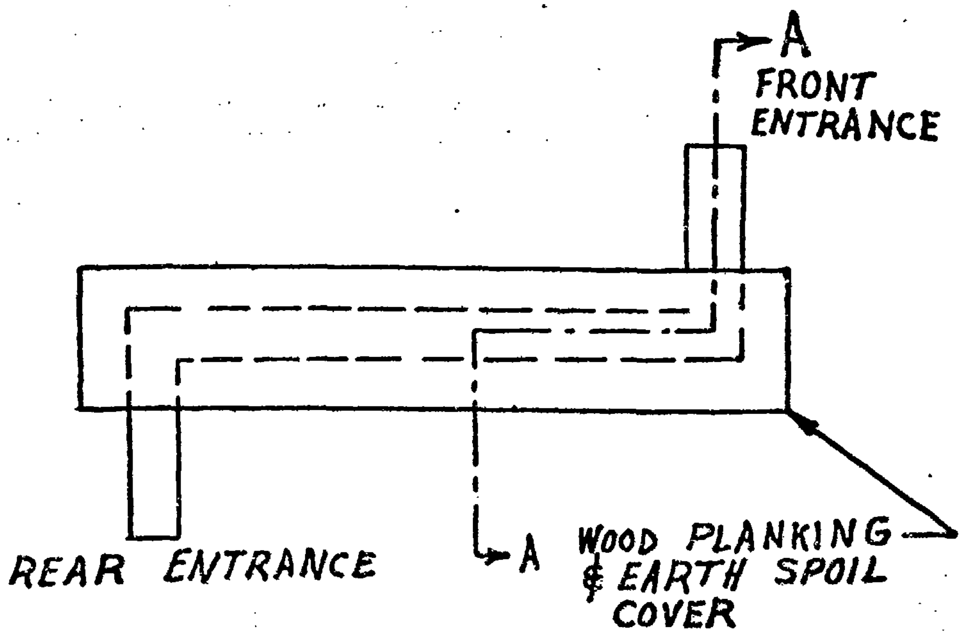
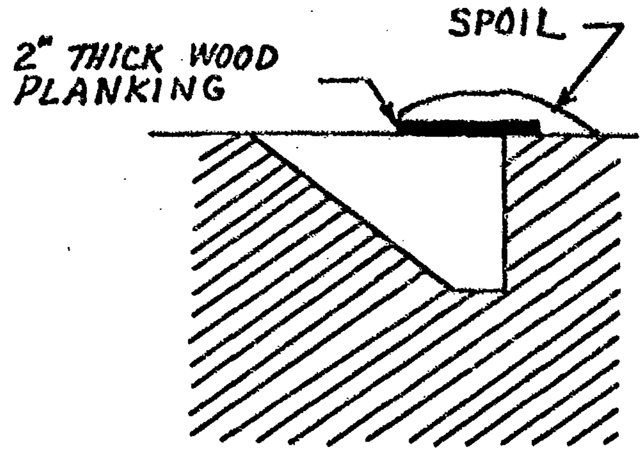


Fig. 4. Communal shelter.

(C) Covered trench shelters, Fig. 5, were tested at Operation TUMBLER. The trenches were 2 ft wide, and the cover support was 2- by 12-in. planking overlapping the sides of the trench by at least 2 ft. The cover was 2 ft of soil. In this particular test, the 2- by 12-in. planking withstood 15 psi but not 20 psi (28). (C)





SECTION A-A

Fig. 5. Covered trench shelter.

A special type of cover support is currently in use in military field fortifications. Revetment can be incorporated into this structure quite easily since the structure provides adequate bracing. This structure consists of posts, caps, and stringers with diagonal bracing on the posts. The cover in this case is supported by stringers placed perpendicular to the major shelter

axis. These stringers, which are uniformly loaded, act as simple beams. The stringers in turn are supported by caps placed parallel to the major shelter axis. The caps act as single-span fixed-end beams or multi-span beams. The caps in turn are supported by posts which act as columns with one fixed end. Further strengthening is provided by a single diagonal brace between successive posts. This brace is ordinarily eliminated when timber sheathing is used as a reveting material and is supported by the posts. Transverse bracing is provided across the top width of the shelters between opposite posts and on a level with the caps. This brace reduces head room but is necessary for rigidity. Usually, footings are not employed for the posts; however, they may be necessary in very soft soil.

The foregoing structure can be designed in modular section, Fig. 6, which then can be formed in multiples for larger shelters. In a modular section, there would be provided four posts, four caps, and the necessary stringers and diagonal braces. The stringers should be placed in two or more layers in different directions to provide equivalent load distribution on the caps. In multiple sections, all posts except the end posts and all caps across the width of the shelter except end caps should be designed for twice the load of the others. In multiple sections, the modular units could be placed adjacent to each other with a certain amount of fastening, but this would not provide the high continuity that

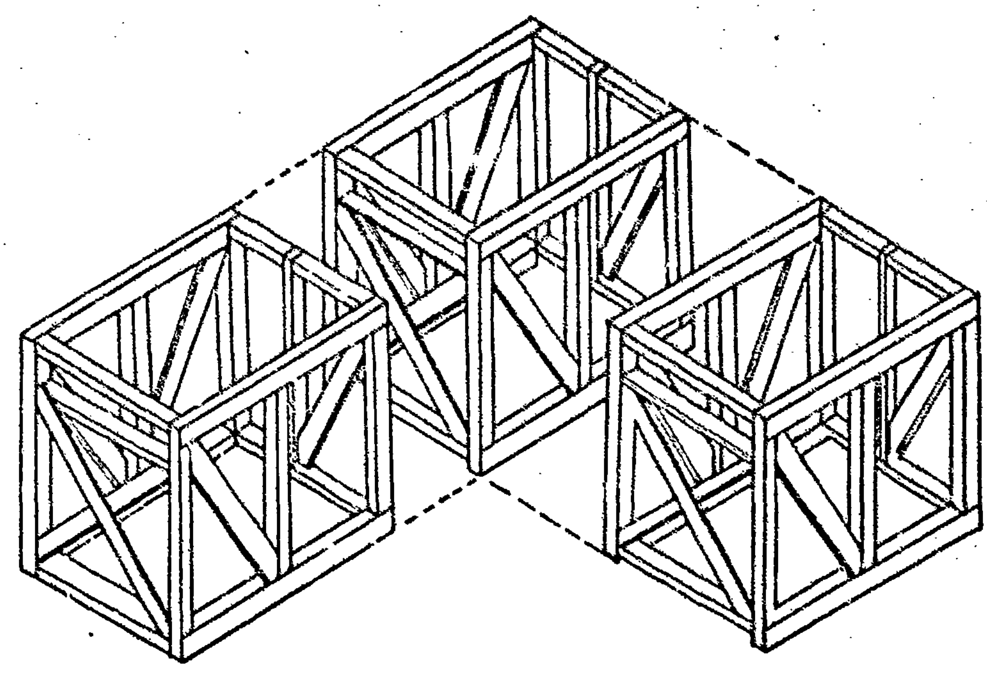


Fig. 6. Modular sections.

increasing the size of posts and caps at the joints between the modular sections would provide.

Testing conducted at Fort Belvoir during 1956 and 1957 gave indications that laminations within the cover support would be of definite value, particularly when subjected to dynamic loads of short duration. The cover support consisted of simple beams placed across an open fortification and supporting 18 in. of earth cover. One structure was 4 ft square, unsupported span length, and another was 9 ft square. The smaller structure utilized beams 6 in. deep, and the larger one utilized beams 8 in. deep. A comparison was made between 8- by 8-in. or 6- by 6-in. solid beams and 1- by 6-in. or 1- by 12-in. laminated beams arranged in equivalent depths. The 1-in. beams were placed at right angles in alternate layers, giving a better distribution of point loading. A sufficiently large charge of TNT was detonated on top of the earth cover to cause failure of the beams. Failure of the laminations was limited to the bottom two or three layers. Results of the tests showed that it required two to three times as great a charge to cause failure in the laminations as it did to cause failure of the solid beams. Testing also showed that a cover support consisting of multiple saplings, maximum diameter 3-in., was very effective against high explosives. Correlating the data from these tests with atomic blast effects is not simple. Blast pressures from H. E. weapons vary as the cube root of the ratio of the charge weights. Therefore, even though the charges were 250 to 300 percent greater, the peak pressures were only 35 to 45 percent larger. Also, blast duration times for H. E. weapons are extremely short as compared with atomic weapons. However, these data do show that a laminated cover support would withstand the blast effects of an H. E. shell containing twice the explosive charge that a solid timber cover support of equal weight and thickness would withstand.

The "radiological shelter" requires sufficient thickness of material in the shelter walls and roof to reduce the gamma radiation dose by a factor of 1000 or more. This would require at least 3 ft of earth or its equivalent in other materials. Attention would also have to be paid to details of the entrances and ventilation system to prevent fallout material from entering the shelter in significant amounts. A "radiological shelter" will also provide complete protection against the direct heat flash from detonation and will also offer considerable protection against air blast. In most cases, protection against a blast overpressure of 10 psi can be expected as a byproduct of the requirements for radiological protection. Very simple underground shelters constructed of sandbags and wooden planks have been judged to provide blast protection against an overpressure of 10 psi (29).

c. Revetment. A revetment is a retaining wall or facing for maintaining an earth slope at an angle steeper than its natural angle of repose.

In loose or granular soil, measures must be taken to prevent crumbling of walls when the position is to be occupied for more than a few days. Decreasing the slope for this purpose decreases protection afforded by the emplacement. Revetments require considerable labor and material, but they reduce maintenance and insure stability of the earth slope. Earth walls in entrenchments and emplacements not only are subject to normal erosion processes and wear and tear of constant occupation, but they must also withstand heavy earth shock caused by explosion of bombs and artillery shells. There are two types of revetments, the retaining-wall type and the surface or facing type (30).

The retaining-wall type is strong enough to retain a dirt wall without extra bracing or supports. Dimensions of the excavation must be increased to allow space for this type of revetment. Examples of this type of revetment are sandbags, logs, and expedient materials such as empty ration crates, empty shell cases, or ammunition boxes filled with soil (30).

Surface or facing revetment serves mainly to protect the revetted surface from effects of weather and damage caused by occupation. When strongly constructed and supported, revetment retains loose material. Issue material such as burlap and chicken wire, wire mesh, or corrugated metal sheeting could be used in constructing revetments. When installed, these materials are held in place by metal or wooden pickets which are driven into the floor. Brush and cut timber can be used as natural facing revetment. A brush revetment is constructed by driving pickets at 1-pace intervals in the trench floor. Space behind the pickets then is packed with small, straight brush laid horizontally. A cut-timber revetment is the principal natural means of revetting foxholes and emplacements. It is similar to the brush revetment, except that a horizontal layer of small timbers cut to fit the length of wall to be revetted is used in place of brush. When available, dimension lumber may be used in a similar manner (30).

Ordinary sandbags should be used only for temporary revetting. Where bags are to be in place for a month or longer under average moisture conditions, they must be rotproofed or filled with soil partly stabilized with cement or bitumen. Sandbags are usually placed against earth walls with slopes 3 on 1 to 4 on 1 and with a thickness equal to two sandbag widths or one sandbag length. They are then placed at 90 degrees to each other in alternate layers (30).

It was previously stated that an economical degree of protection against H. E. weapons has in the past been generally established on the basis of a 500-lb,GP bomb detonating at a distance of 25 ft. Three ft of sandbags and 30 in. of packed soil have proved 95 percent effective at 25 ft and 100 percent effective at 40 ft against blast and fragmentation (1).

Revetment for protection of personnel may be provided by piling sand bags filled with sand or earth stabilized with cement to a height of 3 ft 6 in. The sand bags should be protected by earth sloped at 45 degrees (31).

Lateral earth pressures (produced by air pressures applied at the top surface of the soil) exerted on vertical faces of a buried structure are relatively small for well compacted silty soils even when the vertical pressures are high. It appears that pressures on the order of 15 percent of the vertical pressure are reached in the horizontal direction for such soils. However, this ratio may be higher for plastic clays or for granular materials such as sand and would probably be much higher for material carrying water under pressure or for material with voids completely filled with water (26).

(C) Revetment for some FCDA shelters consisted of 1 by 6 sheathing supported at 16-in. intervals by 2 by 4 studs. During atomic tests at Operation BUSTER, this revetment withstood a peak pressure of 15 psi on the surface. A revetment consisting of chicken wire and tarpaper sheathing was adequate where the spacing of supporting members was not too great. Reduction in rigidity of the shelter because of the substitution of chicken wire and tarpaper for 1-in. wood sheathing is not considered serious in structures of basic design. The use of unreinforced concrete-block walls as revetment is not recommended (21). (C)

(C) At Operation TUMBLER, some trench shelters with unrevetted walls were subjected to various blast pressures. Soil structure was a major factor in determining how well the shelter walls withstood blast effects. At one position where the soil structure was fairly good, the walls held at 18.5-psi overpressure; at another position where the soil structure was poor, the sides of the shelter gave way at only 3.9 psi (28). (C)

(C) A number of field fortifications were tested at Operation UPSHOT-KNOTHOLE. These tests included various types of revetment. All the revetments were constructed with a few inches of very loose, fine earth backfill between them and the solid earth walls. Although this loose material may have acted as a buffer, the effect was not apparent. The various revetments were chicken wire and burlap, chickenwire and pasteboard, corrugated metal sheeting, plywood, 1 by 6 timber, and 4 by 4 timber. Results of tests

indicated that these diaphragm-type revetments may be successfully used at ranges from air bursts where the peak overpressures are about 25 psi provided that care is taken to attach them adequately to supports spaced about $2\frac{1}{2}$ ft apart and provided that they are not depended on to add strength or stability to the overall basic structure. Considering general strength, simplicity of construction, and dependability, the 1 by 6 and 4 by 4 timber revetments are superior to the others. Rigidly supported at about 3-ft intervals, a 4 by 4 timber revetment appears to have sufficient strength to stand up at a range from an air burst where the peak air overpressure is approximately 300 psi (10). (C)

Sandbags can be used as a revetting material provided they are protected from direct exposure to thermal rays. Sandbags covered with small amounts of loose earth are not damaged.

There is little information available from past tests on the reaction of various types of revetment to an atomic explosion. It has been generally concluded that all normal types of revetment are adequate for military use, that revetted fortifications can be located at much closer distances to ground zero than unrevetted fortifications can, and that soil structure is a major factor determining how well unrevetted walls will withstand a blast (10).

Because of the unknown nature of the transmission of a shock wave through earth and of the loading of structures by such a wave, required revetment strength is based more on experience than theoretical calculation. In general, the forces applied to revetments have been considerably less destructive than those applied to cover structure by a blast, and relatively light revetment construction has been successful (10).

(C) Wooden shelters tested in Operation BUSTER withstood 15-psi peak overpressure. The revetment was 1 by 6 sheathing supported by 2 by 4 studs spaced at 16 in. (21). (C)

d. Entrances. The entrance is one of the more difficult problems in shelter design. This report does not encompass the design of blast-resistant doors although their design is very similar to that of cover support. The apparently critical item which most blast door designs for improvised shelters have indicated under test is the door supporting frame. Many failures of doors have not been of the door itself but rather of the door frame or support. Pertinent items in the design of entrances will be brought out in the succeeding paragraphs.

Entrances 2 ft 6 in. in width and 5 ft 6 in. in clear height will accommodate stretchers for rescue work. Ramp entrances should not be steeper than one in four.

Provision of emergency exits is important, and at least one emergency exit must be provided for every communal shelter. Emergency exits should be located in the opposite end from the entrance (32).

A test was made to determine the possibility of one person passing another in an emergency exit of circular cross section. A 2-ft 9-in. diameter steel pipe was used. One person was 6 ft tall and weighed 210 lb and the other one was 5 ft 9 in. tall and weighed 185 lb. Since the two persons were able to pass each other, it was concluded that a pipe 3 ft in diameter should be adequate as an emergency exit (33).

The slope of ramps should not be steeper than one in eight, and the slope of stairs should not be steeper than two in three (1).

Entrances for protection against CBR attack should be walled-in passageways fitted with double doors or gasproof curtains about 9 to 12 feet apart. The double doors create an air lock to reduce agent seepage into the shelter; more than one air lock in series will give increased protection. It is desirable to have air locks or doors around a corner from each other and to have two corners or right angles in the entrance tunnel. This tunnel should preferably slope upward to prevent the flow of heavier-than-air gases into the tunnel. Slanting frames are built for gasproof curtains, and the curtains are weighted to hold them in place. Two entrances may be desirable. Each of these should be provided with a pail of soapy water and a brush for cleaning the boots of personnel entering the shelter (20).

(C) During Operation BUSTER, a number of FCDA shelters, Fig. 3, were tested. Above-grade entrance construction was badly damaged, particularly where the entrances were not fully protected by earth cover. Greatest damage was suffered by entrances facing the blast. Two similar shelters at the same distance from ground zero gave different interior gamma doses. The shelter with the entrance facing ground zero received 60-percent greater gamma radiation than the shelter with the entrance oriented 90 degrees to the radial line from ground zero. In below-grade shelters, entrance construction which was above the natural grade was almost completely blown away. The entrances of all structures were considerably weaker than the shelters proper (21). (C)

Previous investigation has shown that the entrance construction of most structures has been considerably weaker than the structure proper and has been almost invariably the limiting factor in blast resistance. Scorching of parts of entrances not directly exposed to thermal radiation has indicated reflection of

some magnitude; however, those entrances requiring at least two reflections of thermal radiation have successfully shielded the interior from high values of thermal radiation. The design and construction of entrances has tended to be slighted. The proper construction of entrances is as important as that of any other part of a fortification (10).

(C) During Operation BUSTER, a communal shelter, Fig. 4, shaped in the form of an H was tested under atomic effects. Double-ramp-type entranceways were the legs of the H, and the shelter proper was the crossbar. The principal axis of the shelter was perpendicular to the radial line from ground zero. Scatter gamma radiation through the entrances was found to vary by a factor of 5; there was a minimum at the center of the shelter and a maximum 3 ft from the entrance. Two successive shots gave increased radiation by factors of 3 and 2. The relative increase in dose was believed to be due to removal of cover over the shelter proper. Surface gamma intensity for the three shots varied from 13,000r to 70,000r. Three ft from the ends of the interior of the shelter, gamma intensity varied from 388r to 880r. The increase in intensity of radiation near the open ends clearly dictates the need for baffling or shielding against scatter radiation. Reflected blast pressures within the shelter were 2 to 4 times as large as surface pressures with the exception of one shot which gave interior pressures only slightly larger than surface pressures. The lower pressures from this shot are attributed to earth swept into the ramps from the previous shots and occupying 20 to 30 percent of the shelter entrance opening. This reduction of the opening functioned as a restriction to the flow (22). (C)

(C) During Operation UPSHOT-KNOTHOLE, two AEC group shelters with special entrance designs were tested for effectiveness against nuclear radiation. The shelters were 48 feet of 90-in. I. D. pipe, buried 3 feet with one end closed. Entrances were parallel to the axis of the shelters which gave two 90-degree turns into the shelter proper. One entrance was a double ramp, Fig. 7, and the

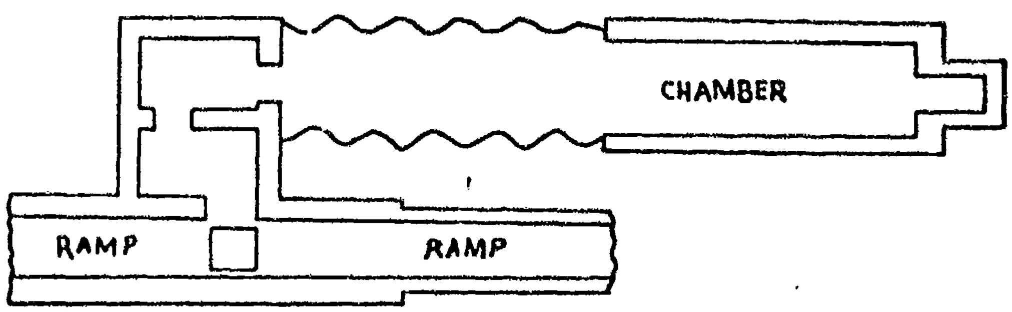


Fig. 7. AEC group shelter.

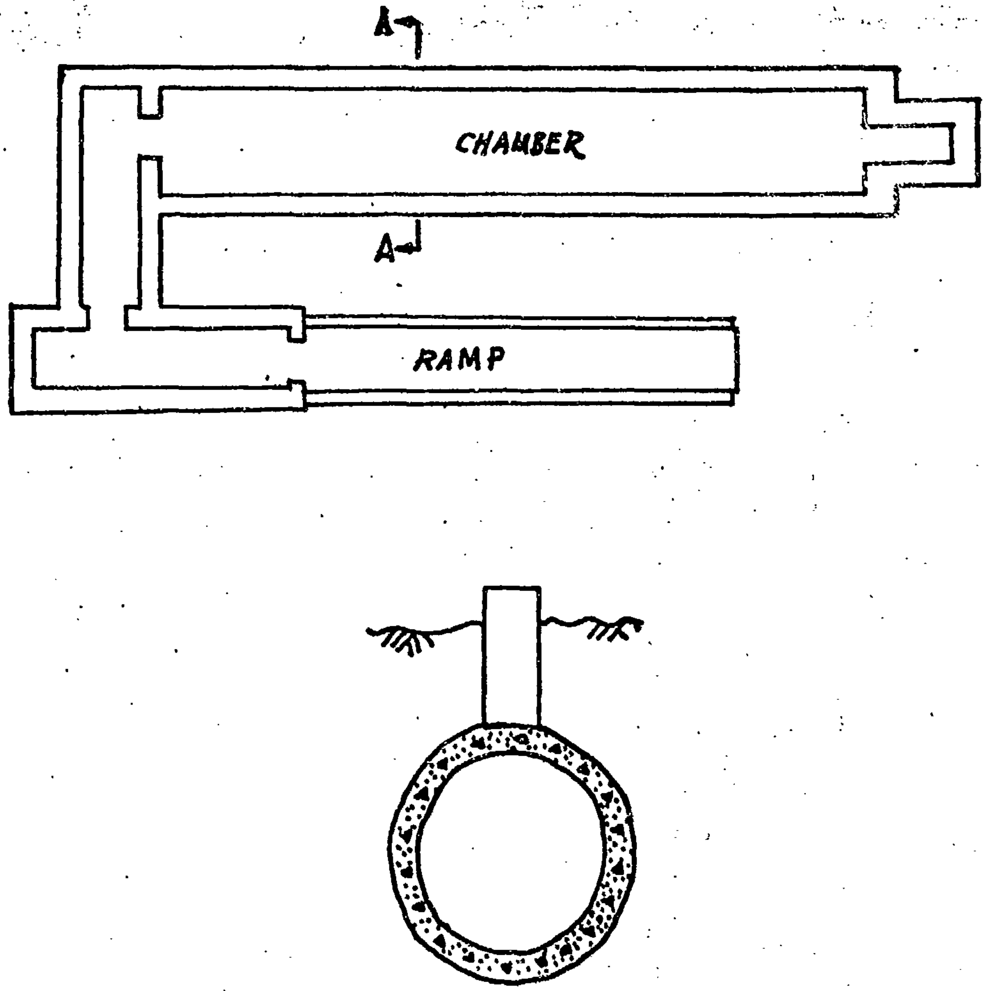


Fig. 8. AEC group shelter.

other, Fig. 8, was a single ramp. The entranceways were efficient in reducing the amount of radiation into the shelter. The gamma radiation was higher in the entrance end of the shelter. There was no apparent difference in effectiveness between the two entrance designs (34). (C)

(C) During Operation TEAPOT, a reinforced concrete group shelter, Fig. 9, with a capacity of 50 persons was subjected to the effects of two atomic weapons. This shelter was designed as a completely closed, ventilated type resistant to long-duration blast pressures with 100-psi maximum overpressure. It was tested both as a closed and as an open shelter. The entrance to the shelter was a stairway with two 90-degree turns. The surface entrance to the stairway was flush with the ground surface and thus avoided

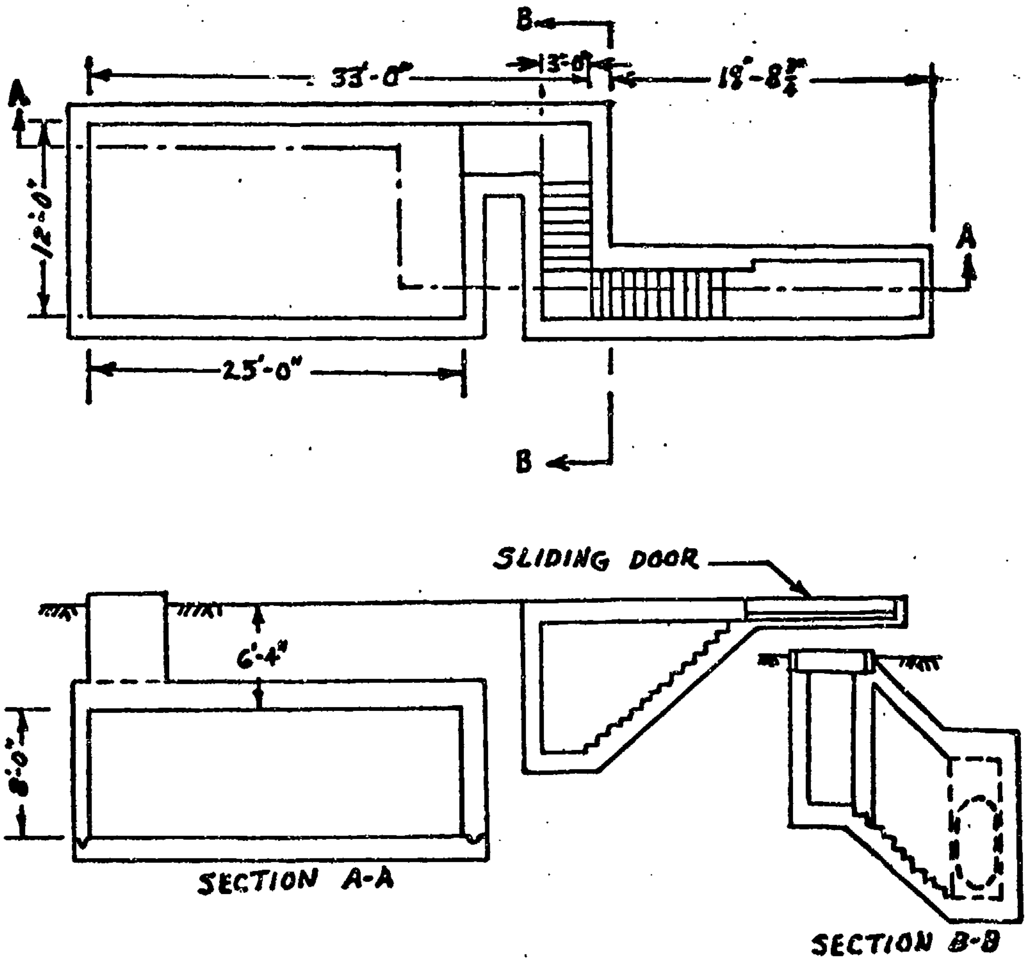


Fig. 9. Group shelter.

high reflected pressure which a vertical door would have experienced. The first 90-degree turn was located at the stairway landing halfway down while the other 90-degree turn was at the base of the stairway and led into the shelter proper. When the shelter was tested as an open shelter, gamma radiation of 23,000r at the surface for the initial shot was attenuated to approximately 3500r at the first landing, 325r at the second landing, and 6r within the shelter proper. Directly below an open ventilation pipe, a total of 50r was measured. Gamma radiation of 57,000r at the surface for the second shot was attenuated to approximately 50,000r at the first landing, 900r at the second landing, and 60r within the shelter proper. Blast attenuation was considerably less. Surface blast overpressures of 47 and 92 psi for the same two shots were attenuated to 26-37 psi and 64-74 psi, respectively, within the shelter proper. Apparently, there was

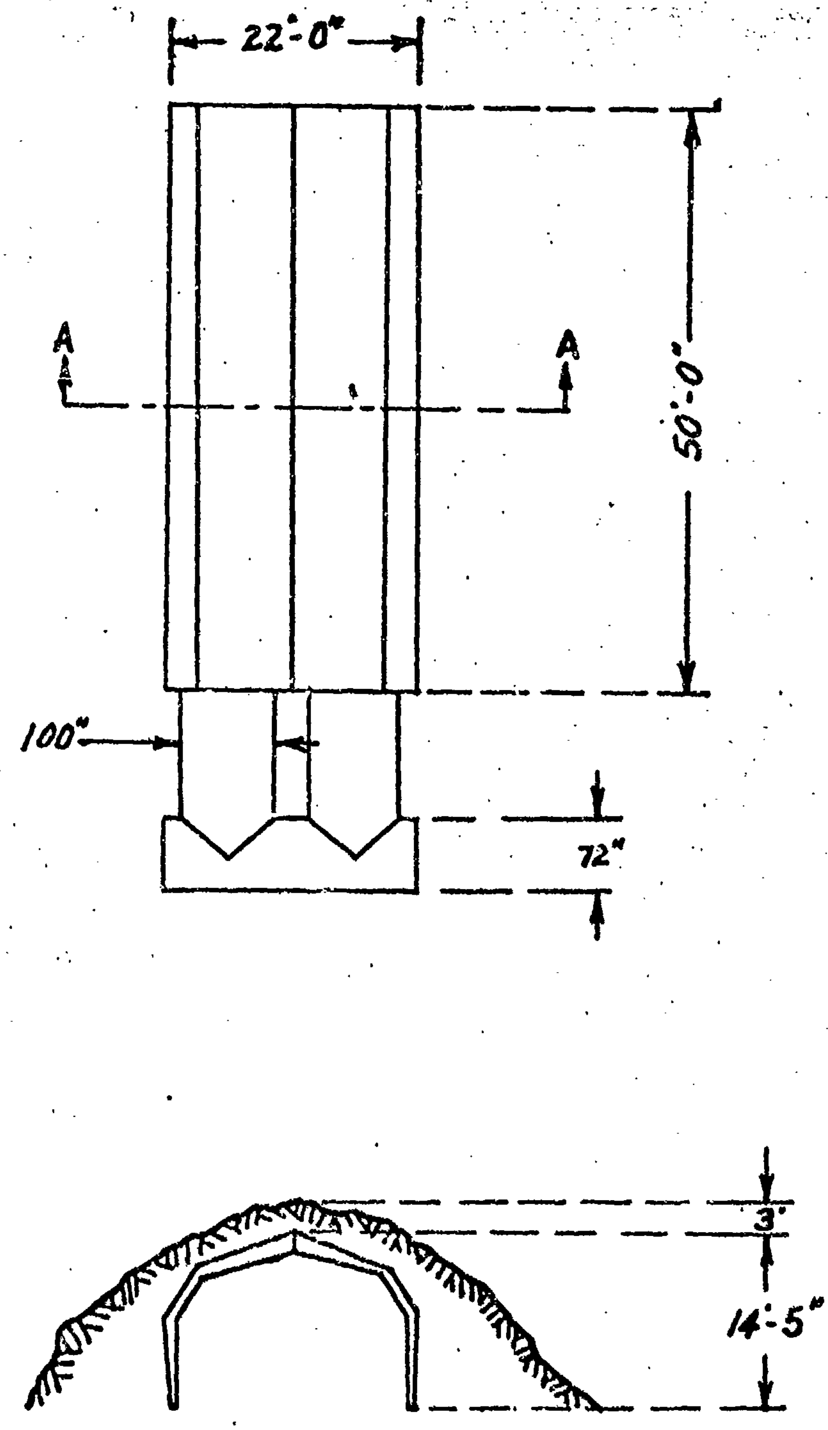
no entry of reflected thermal energy into the shelter proper; however, heated air of high temperature, 150-350 C, did enter. The high temperatures were of such short duration that only the fur of test animals was singed. When the shelter was tested as a closed shelter, there was no damage from outside overpressures of 47 and 92 psi or from thermal effects. Gamma attenuation was excellent. On one shot, 8500r just below the door was attenuated to less than 1r within the shelter proper. On another shot, 25,500r just below the door was attenuated to 1 to 2r within the shelter (35). (C)

(C) Thermal energy measurements at Operation BUSTER indicated that soil would reflect only a small amount of thermal energy. Measurements were made in a foxhole, 6 by 2 ft wide and 4 ft deep. Eighteen cal/cm^2 was measured on the rear wall of the foxhole. Only 1.3 cal/cm^2 was measured on the front wall. Measurements on the side walls indicated no significant energy. This data indicates that a soil-lined entranceway will admit only a small amount of thermal energy if one or two bends are incorporated (12). (C)

(C) The very long duration of an atomic blast wave insures that pressure rise inside a surface shelter with open door will be comparable with that outside. If the door area is small, however, compared to cross section of the shelter, pressure rise inside the shelter will be gradual. For a given volume, therefore, a shelter in the form of a long narrow tunnel would present the greatest hazard (36). (C)

(C) During Operation UPSHOT-KNOTHOLE, testing was conducted on a gable-shaped group shelter, Fig. 10, constructed of concrete panels. This structure was covered with earth several feet deep. Access to the doors and air inlets was by means of corrugated metal pipe through the cover. The pipe to the air inlets was 24 in. in diameter. The pipe to the entrance was 72 in. in diameter except for the small section nearest the doorway which was 100 in. in diameter. This pipe contained one right-angle turn. The door in the entrance was blast resistant. The shelter was subjected to blast pressures varying from 7 to 11 psi. The structure was only slightly damaged, although blast entered the air intake and destroyed the filtering units and blew over some interior partitions (37). (C)

(C) During Operation UPSHOT-KNOTHOLE, dogs were placed in communal shelters and exposed to the blast effects of two atomic detonations. The shelters, Fig. 11 and Fig. 12, were large pipe covered with earth. Entrances were ramp type containing two right-angle turns into the shelter proper. For the initial shot, the ramps were oriented parallel to the direction of the blast wave; for the second shot, the ramps were oriented perpendicular to the direction of the blast wave. The two principal conditions affecting pressure within the structures were outside overpressure and



SECTION A-A

Fig. 10. Gable-shaped group shelter.

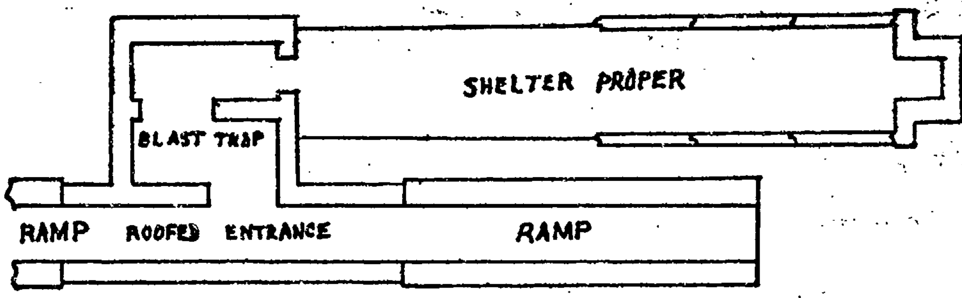


Fig. 11. Communal shelter.

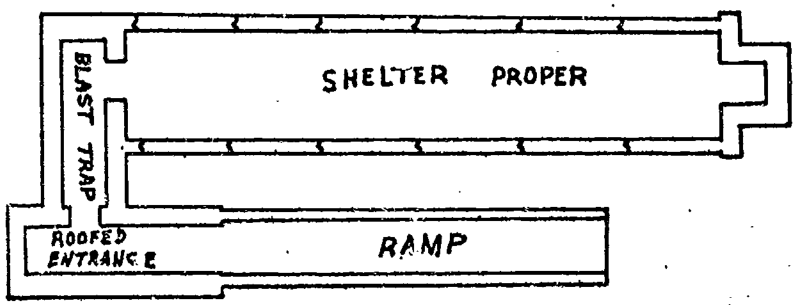


Fig. 12. Communal shelter.

orientation of the entrance ramps with respect to direction of the blast wave. In addition, it appeared that volume of the structure with respect to entrance area was such that little or no reduction in peak overpressure would occur. The outside peak overpressures were 12 psi and 13 psi, respectively, for the initial and second shots. From the initial shot (ramps aligned parallel to direction of blast), the animals sustained marked blast damage (hemorrhages in lungs and abdominal organs), three dogs were ataxic, and two dummies were violently displaced. From the second shot (ramps aligned perpendicular to direction of blast), no significant injuries to the animals were found and the dummies were minimally displaced. The greater damage was caused by the smaller peak outside pressure. Rather violent displacements resulting in significant secondary injuries may, therefore, be anticipated in occupants of such shelters where entrances are aligned parallel to the direction of the blast wave (38). (C)

During and prior to World War II, relatively simple devices were used to protect against the blast of H. E. bombs and shells. For instance, almost any type of overlapping baffle wall is effective in protecting a door, and a simple bend or offset is

usually sufficient to protect a duct against an H. E. blast which is generally characterized by a very short wave length compared to the size of the protecting devices. However, the long wave length of an atomic blast completely envelops and fills these simple protection devices before the positive phase has passed, thus rendering them relatively ineffective (39).

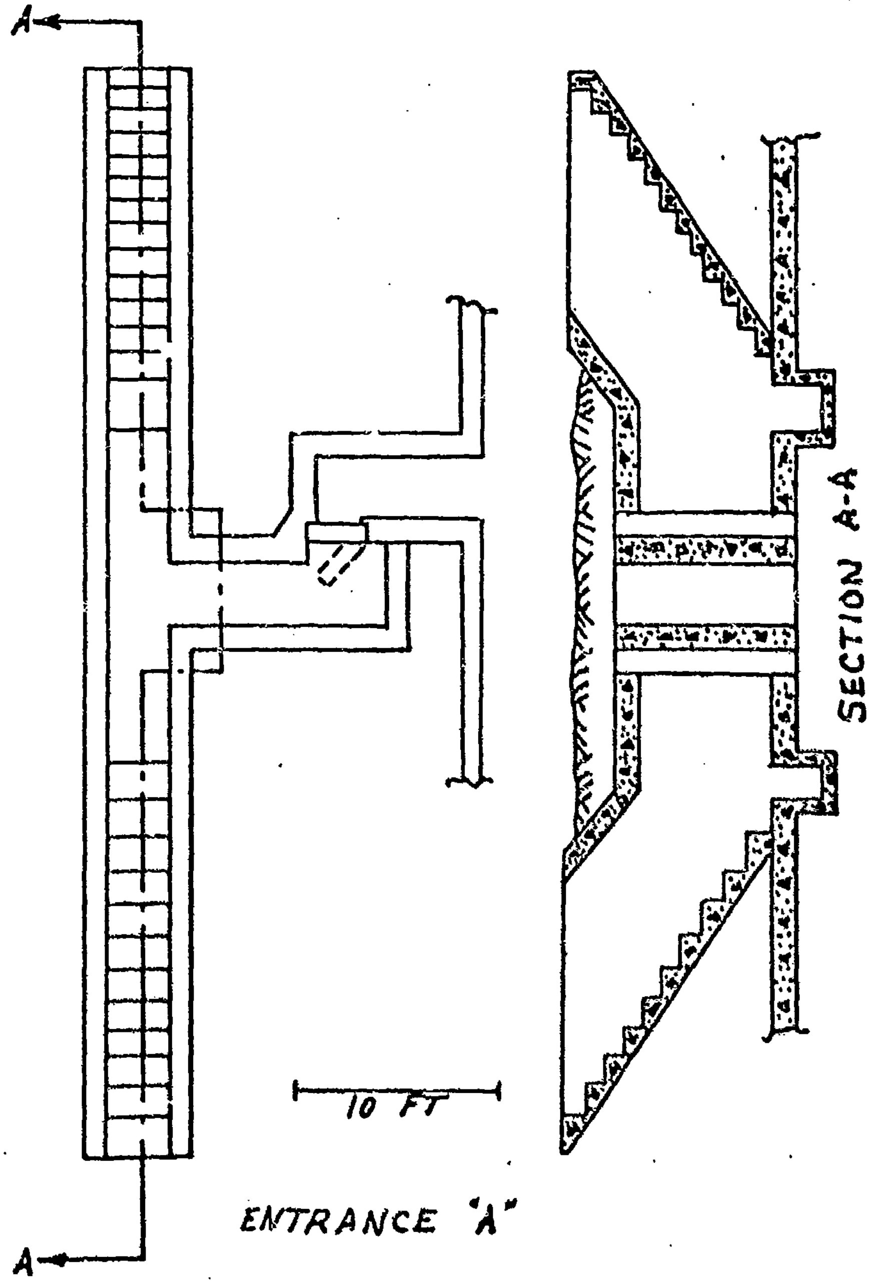


Fig. 13. T-shaped double stairway entrance.

(C) The primary purpose of the UPSHOT-KNOTHOLE project was to obtain information on the behavior of shock waves in entranceways, and to study attenuation of such shock waves in entranceways of practical design incorporating baffles and turns. The two entranceways which were included in the tests were rather simple in design. Entranceway A, Fig. 13, was a T-shaped double stairway. Entranceway C, Fig. 14, had only one stairway, but it had six right-angle bends. Location of the blast doors in the two entranceways was determined by two primary conditions: (1) the door should not

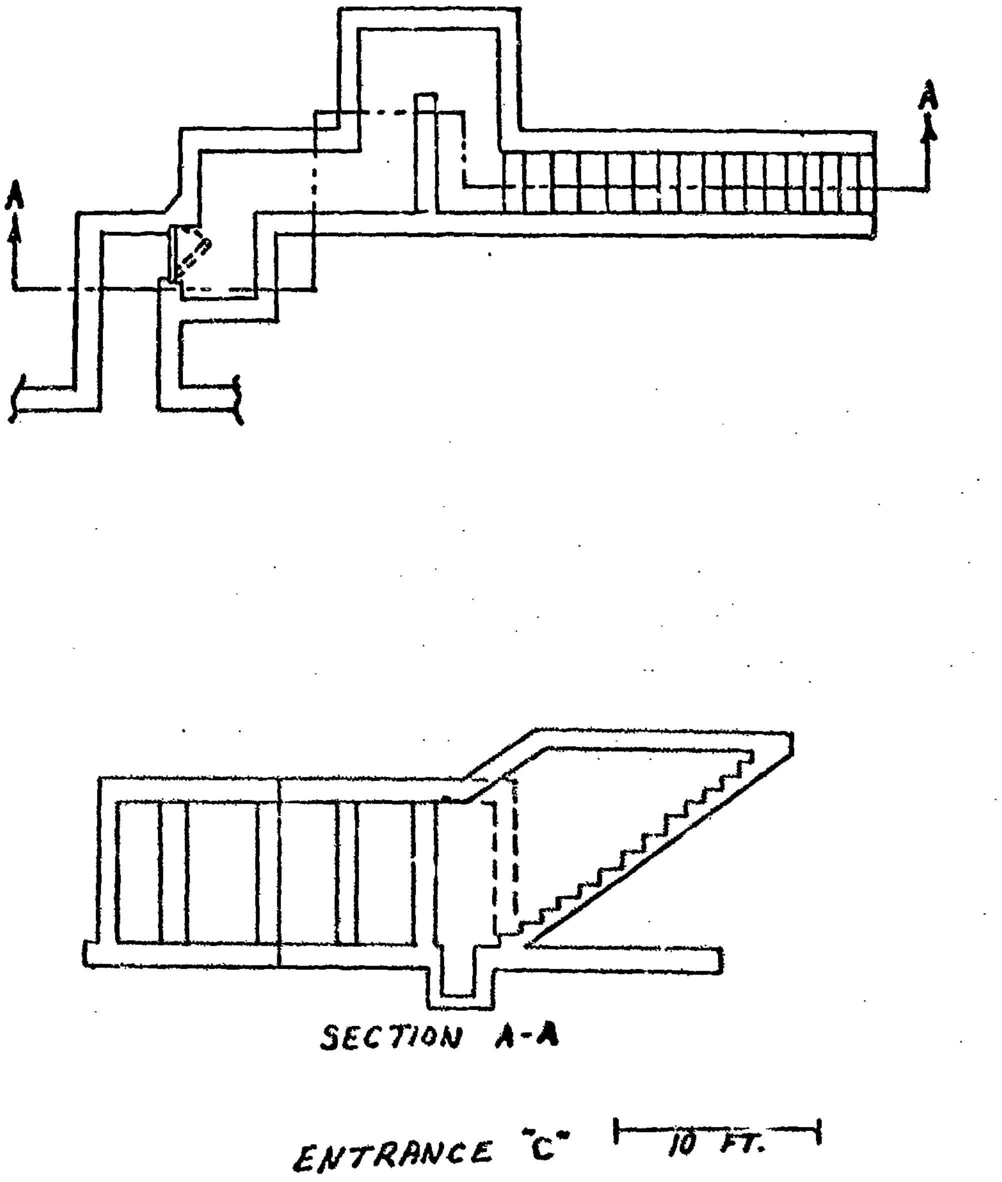


Fig. 14. Single stairway entrance, baffled.

be exposed to the direct effect of the shock wave, and (2) the door should be placed so that it would not be hurled through the structure in the event of failure. Therefore, the blast doors were placed at the structure end of the entrance; in addition, one right-angle bend was placed between the door and the shelter proper. Records from the gages in the entranceways were very irregular when the shelters were subjected to a peak surface overpressure of 21 psi. In general, pressures measured in Entranceway A (T-shaped) were higher than those in Entranceway C (baffled), and pressures in both were higher than outside pressure. The average maximum pressure near the steel door in Entranceway A was approximately 75 percent higher than the peak external pressure; the average maximum pressure near the steel door in Entranceway C was 35 percent higher than the peak external pressure (39). (C)

(C) If an entranceway is restricted in size and leads to an extremely large chamber, it may act as a ventilating duct, and pressures in the chamber can be computed. Whatever baffles or turns and corners are provided in the entranceway, dictates of economy are such that total length of the entranceway cannot be much longer than that required for access to the surface from the structure. It is probably always cheaper to provide a resistant door to the shelter than it is to provide a very complicated entranceway. For the major part of the time of the shock for a moderate or large size bomb, the entranceway and doorways leading off the entranceway are subjected to pressures corresponding to those in the air in the general region of the structures. It does not seem possible that entranceways which do not involve major changes in cross-section through their lengths can provide any material attenuation of a shock wave passing through them. An entranceway with a series of expansion chambers and surfaces from which reflections can be obtained, so as to "choke" the passage between one expansion chamber and the next, may provide for a major attenuation. However, such a passageway might be much more expensive than a simple door at the entrance. Nevertheless, this kind of passageway may increase materially the time of rise to maximum pressure acting on a door at the end of the passageway. A characteristic indicating passage of shock into and through the passageway to the farthest point, a reflection, and a passage back to the entrance shows roughly through all the records. Maximum pressures occur in this reflected shock wave where it reinforces the primary pressure wave. The magnitude of the maximum reflected pressure is approximately twice the peak outside pressure which enters in the first place. The entranceways tested would have been extremely effective for H. E. weapons or, in fact, for any short-duration shock waves. Their effectiveness for longer-duration pulses decreases, and it is questionable whether any type of entranceway would be capable of "breaking up" a shock or of reducing the pressures on doorways below the external pressure for a weapon of large size which produces a shock wave of long duration (39). (C)

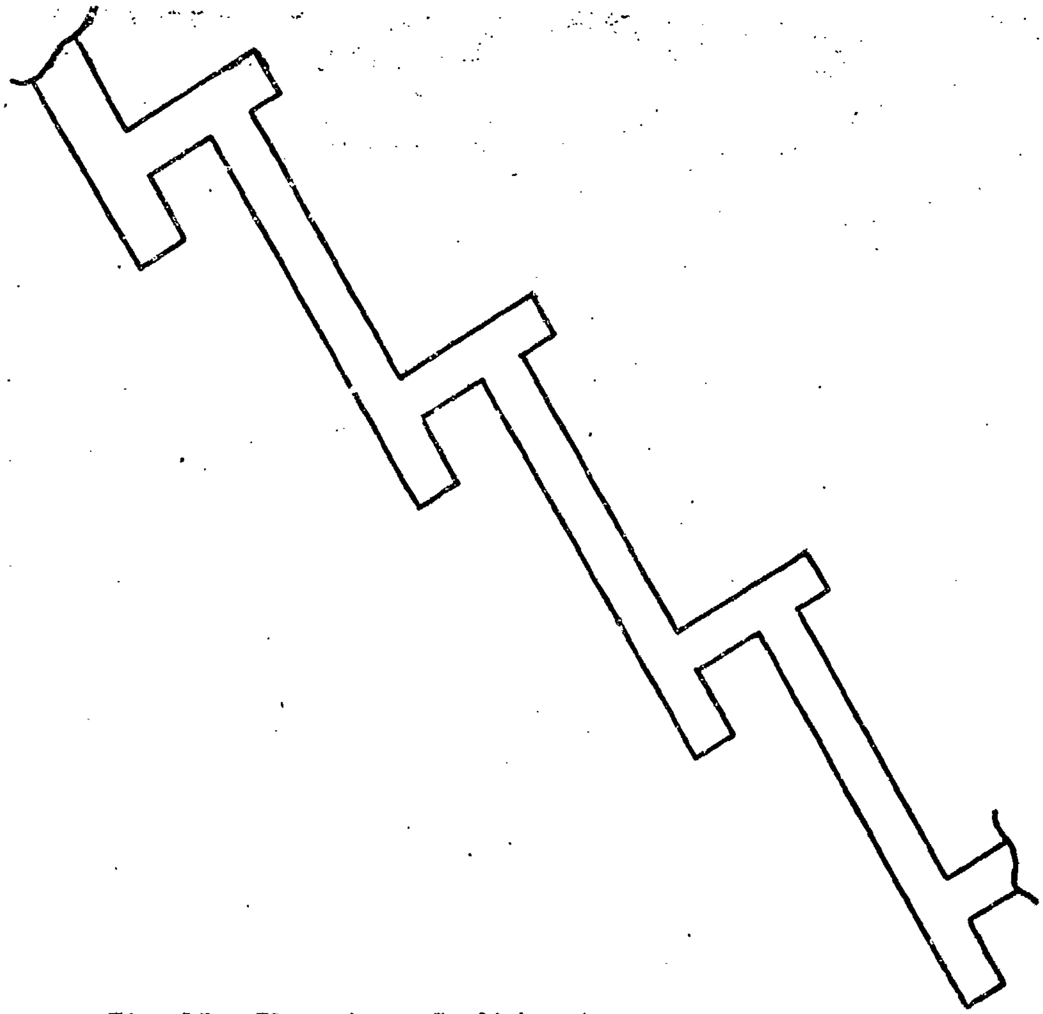


Fig. 15. Plan view - Swedish entrance.

A multiple blast-trap-type entrance, Fig. 15, is currently viewed with favor in Sweden.

e. Blast Walls. Blast walls are designed to protect an entrance to a shelter from fragmentation and blast waves. They are utilized with entrances which open above original ground. Such a wall is particularly effective against H. E. weapons although the same results can be accomplished by a bend in the entranceway. The long duration of atomic blast pressures makes the blast wall quite ineffective against atomic blast waves; however, it is effective against missiles. The incorporation of bends in entranceways, apparently considered essential in atomic shelters, will render blast walls unnecessary. Blast walls can to a large extent eliminate the entry of drag forces from an atomic explosion into the entranceway;

however, they may cause a reflection into the entranceway when the blast waves come from another direction.

f. Ventilation and Capacity. Ventilation of emergency or improvised shelters will of necessity have to be natural. Mechanical ventilation of some type may be incorporated at a later date if and when necessary. Shelters may be closed or open. Ventilation will particularly affect the number of personnel which may occupy any size shelter.

Because fallout may require occupants to remain in a shelter for a number of days, at least 10 sq ft and 65 cu ft of space per person should be provided with room for at least half of the occupants to lie down at one time. Whenever feasible, up to 15 or 20 sq ft per person should be provided. Mechanical ventilation with filtered air is not considered essential for small shelters. During an emergency, the door of a small shelter can be opened occasionally to replace the air. A small vent pipe through the roof terminating in a raincap will help to remove stale or contaminated air (40).

The most important characteristic affecting shelter costs is the number of square feet of shelter space to be allotted per occupant. This factor depends in turn on the maximum time the shelter must be occupied. Studies at the U. S. Naval Radiological Defense Laboratory indicate that under fallout conditions, shelters will be occupied at least three days and for as long as two weeks under some circumstances. It is recommended that shelters be designed for a two-week occupancy even though the "average" shelter stay may be somewhat shorter than a week. Since, according to available literature, no actual tests have been made of shelter habitability as a function of the area allotted each occupant, only approximate estimates of space requirements can be given (29).

As a first approximation, each occupant must be assigned sufficient floor space in which to sleep plus his share of the space required for food, water, aisles, etc. A space requirement of 20 sq ft per person is arrived at in the following way. Each person is allocated an area of 15 sq ft for living and sleeping. This area is approximately the size of a standard army cot $2\frac{1}{2}$ ft wide by 6 ft long. Space requirements for food are based on the Army Food Packet, Individual Assault 1A. A case containing 24 meals occupies approximately 1 cu ft. Assuming that cases can be stacked six high on the average, each sq ft would contain a two-week supply of food for three people. This amounts to 0.34 sq ft per person. Army Field Manual 5-34 states that one-half gallon of drinking water is the minimum per person per day for no longer than three days. One gallon is recommended. This amount contains some allowances for cooking and personal hygiene. Allowing 14 gallons of potable water

per person and assuming that the potable water tank is 4 ft high, the floor space requirement per person is 0.47 sq ft. Adequate toilet space can be provided on an area of 0.32 sq ft per person. Certain control operations must be carried out in the shelter. These functions will use 0.5 sq ft per person. Passageways are necessary for the movement of personnel. The total of these requirements is 19.63 sq ft or approximately 20 ft per person. These space requirements are summarized in Table X (29).

Table X. Personnel Space Requirements

Space Required Per Person in Shelter*

Space	Area (sq ft)
Living and sleeping	15.00
Food for 2 weeks	0.34
Water for 2 weeks	0.47
Toilet space	0.32
Operating space	0.50
Passageways	3.00
Total required	19.63**

Notes: * Table based on using floor for sleeping. If double-decked sleeping arrangements are provided the space requirement is 10.38 sq ft.

** This space requirement is about twice that used by the FCDA. On the other hand, it is about one-half the standard used in Army field shelters.

Since shelter costs are heavily dependent upon the space requirement, it would be very important to reduce the space requirement to a minimum. This can be done by sleeping the occupants in shifts or by providing double- or triple-decked sleeping facilities using a simple canvas-covered pipe frame. The figure used in most shelter designs is about 10 sq ft per person. It appears important to conduct habitability tests to resolve the question whether 10 sq ft is sufficient (29).

Existing data indicate that shelter costs rise slowly with increasing size of shelter. Therefore, the size of the individual shelter should be determined by the maximum number of people that can reach it in an acceptable length of time after warning of attack. However, problems of morale and discipline can arise when large groups of people are assembled under trying circumstances. Military experience suggests that group size should be restricted to 50 to 100 persons (29).

A shelter can be completely closed, with no ventilation whatsoever, for 15 hours when interior volume per person is at least 300 cu ft (29).

For inactive personnel in unventilated shelters, 1 cu ft of air per minute per man is required. Table XI suggests dimensions for unventilated shelters occupied by up to 50 men, the practicable maximum.

Table XI. Protective Shelter Requirements

Number of Occupants	$2\frac{1}{2}$ Hr Air Requirements (cu ft)	Suggested Dimensions (ft) Length	Width	Height
1	150	7	4	7
15	2250	20	15	8
30	4500	29	18	9
50	7500	34	23	10

(C) A test of various ventilating ducts was conducted during Operation UPSHOT-KNOTHOLE. Six different vent designs were utilized in the test. Two of the vents were 6-in. straight pipe, one of which had a T-shaped entry while the other had a 180-degree bend entry. A heavy-duty muffler-type blast baffle was incorporated into a 6-in. pipe with a T-shaped entry to form the third vent. The fourth vent was the Swedish rock grille which consisted of a concrete box filled with cobblestones supported on bars extending across the chamber. The interior chamber is 4 ft square by 4 ft 6 in. deep. The final two vents were 6-in. pipe containing a set of Chemical Corps filters. Each set included one particulate filter and one charcoal gas filter. Both vents had a T-shaped entry while one was further protected by a Chemical Corps antiblast closure valve. The ducts from the vents into the chamber were 6-in. diameter with the exception of the one from the Swedish rock grille which was 12-in. diameter. The vents were subjected to a peak surface overpressure of 21 psi. Measurements were made of the peak pressure in the vents and of the maximum sustained pressure within the vents and the shelter chamber. Recorded pressures are shown in Table XII (39). (C)

Table XII. Maximum Vent Pressures (C)

Vent	Gage Location	Initial Peak (psi)	Maximum (psi)
T-Shaped Entry	Duct	10.4	7.5
	Chamber		7.8
180° Bend Entry	Duct	11.4	7.6
	Chamber		8.2
Swedish Rock Grille	Duct	2.2	9.7
	Chamber		11.2
Muffler	Duct	4.7	5.0
	Chamber		5.2
Filters	Duct	0.8	2.6
	Chamber		2.3
Anti-Blast Valve and Filters	Duct	0.4	0.3
	Chamber		0.3

(C) The blast curves from the duct gages were characterized by a very rapid rise to a peak pressure followed by a rapid fall to a pressure less than half of peak, then a gradual rise to a sustained maximum pressure followed by a gradual fall to zero, and then a negative phase. The vent containing the filters and anti-blast closure valve permitted only a very small increase in pressure indicating that the closure valve functioned correctly. These pressure-time curves show that all of the vents appreciably lengthened the rise time in the shelter chambers and in some cases reduced the maximum pressure by a large factor. However, a peak or spike occurred in the pressure records for the ducts. The initial peak is caused by the shock front. It is followed by a gradual build-up in pressure to a maximum which is controlled by the resistance of the vent to the flow of air. Since the chamber volume is largely relative to the cross-sectional area of the duct, the chamber pressure gages do not show any evidence of an initial peak but build up gradually to a maximum. The maximum pressure as measured in the chamber is usually slightly higher than that measured in the duct as would be expected from consideration of the flow conditions. The two straight pipe vents gave approximately the same results. The vent pipe containing the muffler gave better results than the straight pipes, while the two vents containing the filters were the most efficient, particularly the vent containing the closure device. A first glance at the Swedish rock grille would indicate that although it is quite effective in preventing the entrance of the shock front, it presents very little resistance to flow in the latter stages of the test. However, it must be remembered that the duct in this

chamber was 17 in. in diameter while the other ducts were 6 in. in diameter. The flow is throttled or impeded in its passage through the duct by an amount dependent on the configuration of the duct. Throttling of the flow through a ventilating duct is obtained in part by the restriction in flow and in part by the obstacles or baffles which are interposed. In other words, a 12-in. pipe will permit considerably higher pressure to enter a structure than will a 6-in. pipe. The most effective throttling device appears to be a quick-acting blast valve. However, such devices are difficult to make rugged enough for extremely high pressures. There is a question, however, whether any type of throttling device except a quick-closing valve will be suitable for extremely long durations of pressure (39). (C)

For effectiveness against CBR attack, the shelter should be completely sealed. All vents, entrances, and exits must be closed (20).

Table XIII. Minimum Ventilation and Space Requirements for Protective Structures (1)

Location	Maximum Period of Occupancy (hrs)	Type of Ventilation	Surface Area per Person (sq ft)	Floor Area per Person (sq ft)	Volume Content per Person (cu ft)
Above ground	3	Natural	50	6	50
Above ground	12	Natural	60	6	75
Below ground	3	Natural	30	6	50
Below ground	12	Natural	50	6	75
Above or	3	None	75	6	120
below ground	12	None	100	6	350

The above figures apply to occupied space only; passageways, sanitary arrangements, entranceways, etc., are not included.

Table XIII contains recommended ventilation and space requirements.

Shelters not provided with collective protectors should be used only by personnel who are to remain inactive during occupancy. Since an inactive man requires about 1 cu ft of air per minute, the capacity of unventilated shelters is limited. Initial air-space requirements for shelters for not over 12 men are 150 cu ft per man (30).

Air locks are intermediate chambers between the outside and inside of shelters. They allow passage into the shelters, while preventing interior contamination. The doors at each end of the air lock usually are constructed with standard M1 gasproof curtains. Details of the M1 curtain are available in TM 3-350 (30).

(C) A special tarpaulin has been designed to provide a prefabricated item which when used to cover foxholes, litter patients, etc. will furnish protection against CBR attacks. It can also be used over an entrance as a drape or curtain to provide protection against fallout. It is composed mainly of impervious butyl-coated fabric, but contains diffusion panels to provide filtered air safe for breathing and to carry away carbon dioxide. Prefabrication of the tarpaulin limits field installation merely to set up. All field sealing is accomplished by burying the edges of the tarpaulin in the earth around the foxhole (41). (C)

In surface and cut-and-cover shelters, enough fresh air usually is obtained by keeping entrances open (30).

Unventilated shelters require the following minimum dimensions: floor area per person - 6 sq ft, volume per person - 50 cu ft, surface area per person - 25 sq ft. Whichever gives the least accommodation should be the controlling factor. From the above, it will be seen that even when the highest recommended occupancy is adopted, a shelter will be far from full, and shortage of accommodation and lack of organization of personnel may result in some degree of overcrowding of shelters. A shelter designed for 50 people and having a floor area of 300 sq ft might in a panic be packed to capacity with 300 people. Such crowding could bring about disastrous results (42).

Natural ventilation by the occasional opening and closing of doors will not allow an adequate change of air in the shelter. Nor will it be practical to open and close the emergency exits to provide cross ventilation. Mechanical ventilation for small shelters may be too costly in terms of the total expenditure for shelter. Where economy and material become primary factors, a reasonable solution to ventilation problems may be found in the use of a few roof vents. When the several aspects of ventilation are considered with due regard for factors such as size of shelter, degree of anticipated use, and length of time of expected occupancy, the decision is not one which can be stated generally; but with the various points before him, the planner can reach his own solution. The factors which will determine the amount of air necessary for a shelter are floor area, surface area (walls, floor, and ceiling), volume of the shelter, and number of persons sheltered. Table XIV gives minimum space requirements for providing reasonable comfort in shelters (32).

Table XIV. Shelter Space Requirements

Location of Shelter	Maximum Period of Occupancy (hr)	Floor Area (sq ft/ person)	Surface Area (sq ft/ person)	Volume (cu ft/ person)
Above ground	3	6	30	50
Above ground	12	6	60	75
Below ground	3	6	30	50
Below ground	12	6	50	75

Note: The above figures are based on occupied space only; entrance-ways, sanitary arrangements, air locks, etc. are not included.

For a given number of persons, the size of a shelter is determined by three main considerations, floor space, breathing space, and heat. In regard to heat, the total surface area, floor, ceiling, and walls, is the principal factor; in regard to breathing space, the question is governed by volume of the shelter and the air supply to it. Floor space must be considered in relation to the purpose and shape of the shelter. In small, private, domestic shelters where the occupants wish to sit or sleep in comfort, a fairly large allowance of floor space per head is needed. In narrow shelters, such as trenches or tunnels, space for a gangway is important (33).

The number of persons that can be accommodated in a given shelter in safety and without distress depends mainly on the following factors: the temperature to which air in the shelter is raised during occupation, humidity of air in the shelter, the extent to which air becomes charged with carbon dioxide, velocity of air movement inside the shelter, and the temperature of the inner surfaces of the shelter. These factors depend, in turn, partly on the heat, moisture, and carbon dioxide emitted by the people in the shelter, partly on the prevailing weather conditions, and partly on the characteristics of the shelter itself including the provision, if any, for ventilation. A man in a state of slight activity, e. g., sitting down and talking quietly or playing cards, emits about 400 Btu per hour and about 0.6 cu ft of carbon dioxide per hour. Since the specific heat of air is very low, the greater part of the heat emitted by the occupants must be taken up by and transmitted through the walls of the shelter, unless high rates of ventilation can be provided. In most cases, the latter will not be possible; it is, therefore, of utmost importance that the total surface area of the shelter be adequate to transmit this heat at such a rate as to prevent too great an increase in temperature of the air in the shelter. In order to assist this process of heat transfer, it is desirable that the walls of the shelter should be of solid construction and

not made from materials of low thermal conductivity and low specific heat, such as wood or asbestos paneling. Further, the walls of an underground shelter, particularly if they are in contact with the solid soil, are likely not only to have reasonably good thermal conductivity but also to remain at a fairly low temperature throughout the year (33).

The concentration of carbon dioxide reached in the shelter in a given time depends on the presence or absence of ventilation and on the cubic capacity of the room in relation to the number of occupants. Experience shows that with a mixed population, containing elderly people and children, the carbon dioxide concentration should not normally exceed 2 percent for any length of time. This condition can be met either by providing ventilation or by ensuring an adequate amount of air-space per head in an unventilated shelter (33).

From the foregoing, it will be seen that the two overriding considerations in deciding whether a particular shelter will accommodate a given number of occupants are: (1) that the shelter has a sufficient amount of surface area per occupant to ensure dissipation of bodily heat without causing too great an increase in the temperature of the air in the shelter; (2) that the shelter either has a sufficient rate of ventilation or has a sufficient amount of air-space per occupant to prevent the carbon-dioxide concentration from rising above 2 percent during the contemplated period of occupation. It will be noted that the question of humidity has not been explicitly considered in defining these over-riding considerations. This is because a resting man can tolerate a higher relative humidity if the temperature is not too high. The discomfort caused by high relative humidity associated with high temperature, or what amounts to the same thing, a high "wet bulb" temperature, can, however, be greatly mitigated by providing a rapid rate of air movement. For this reason, the provision of internal fans in a shelter will greatly improve comfort even in the absence of ventilation (33).

For unventilated, gas-tight, above- or below-ground shelters of normal dimensions, the total surface area required per person is as follows: 3-hr occupation - 75 sq ft, 12-hr occupation - 100 sq ft. A normal dimensional shelter has its length, width, and height approximately equal. If the surface area relative to cubic capacity is abnormally large as for instance in narrow trenches, consideration of cubic capacity and air composition may become more important than surface area and vice versa. The high proportion of surface area of a trench compared to the volume of air-space gives the trench shelter a high relative capacity for heat absorption. This fact allows such trenches to be occupied with safety on a scale which corresponds to about 25 sq ft of total surface area per person (33).

g. Location. The following fundamental considerations apply to the location of any protective shelter. Shelters should be accessible to personnel who intend to use them. Shelters should be located so as to provide protection against CBR agents, nuclear weapons, and high explosives. Local weather factors, such as air currents and prevailing winds, should be studied so that the shelter is not located where high concentrations of toxic agents may accumulate. Both terrain and earth texture should be studied in choosing a location. Hillsides generally provide well-drained firm soil which is desirable. The shelter should be underground if at all possible (20).

High ground generally will be preferred for shelter sites because of better drainage. Care should be taken to avoid location over gas, water mains, and subterranean construction. Equally important is the fact that locations near or under hazardous constructions such as tall chimneys, water tanks, tall buildings, etc., must be avoided. Hazardous constructions could cause especially destructive debris loads (32).

h. Elevation. The elevation of the shelter with respect to the original ground level is important, particularly so when the shelter is subjected to the effects of atomic weapons and chemical warfare agents. Placing the shelter below the ground surface tends to increase the intensity of war gases which accumulate in low places. Fragments and blast from H. E. weapons detonating on the ground have little effect against buried shelters except for direct hits. The optimum placement of an atomic shelter is deep enough to provide sufficient cover to protect against gamma rays and neutrons. When a shelter projects above or partly above the ground surface, it is particularly vulnerable to drag forces from an atomic explosion.

i. Radiation Attenuation Factors. The attenuation of prompt gamma radiation by any material is approximately proportional to the density of the material. Therefore, the main construction materials rank in attenuation effectiveness in the following descending order: steel, concrete, soil, and timber. The average energy of the prompt gamma radiation from a nuclear explosion is about 4.5 Mev. The necessary thicknesses of various materials to attenuate gamma radiation of this energy by certain factors is contained in Table XV (2).

Attenuation of prompt gamma radiation which is essentially directional depends on slant thickness rather than on minimum thickness of the shielding material.

Attenuation of neutrons from a nuclear explosion involves several different phenomena. First, the very fast neutrons must be slowed down into the intermediate range; this requires a

Table XV. Prompt Gamma Attenuation Thicknesses (in.)

Material	Density lbs/cu ft	Attenuation Factors 0.5	0.1	0.01	0.001	0.0001
Steel	490	$1\frac{1}{2}$	5	10	15	20
Concrete	144	6	17	35	52	70
Packed Soil	100	$7\frac{1}{2}$	25	50	75	100
Timber	34	22	70			

suitable scattering material, such as one containing barium or iron. These neutrons must then be decelerated into the slow range by means of an element of low atomic weight. Water is very satisfactory in this respect, since its two constituent elements, i. e., hydrogen and oxygen, both have low atomic weights. The slow neutrons must then be absorbed. This is not a difficult matter, since the hydrogen in water will serve the purpose. Unfortunately, however, most neutron capture reactions are accompanied by emission of gamma rays. Consequently, sufficient gamma attenuating material must be included to minimize the escape of gamma rays from the shield (2).

In general, concrete or damp earth would represent a fair compromise for neutron, as well as for gamma ray, shielding. Although these materials do not normally contain elements of high atomic weight, they do have a fairly large proportion of hydrogen, in the form of water, to slow down and capture neutrons as well as calcium, silicon, and oxygen to absorb gamma radiation. A thickness of 10 inches of concrete, for example, will decrease the neutron dose by a factor of about 10; 20 inches of concrete will provide a decrease by a factor of roughly 100. Damp earth may be expected to act in a similar manner (2).

An adequate neutron shield must do more than attenuate fast neutrons. It must be able to capture the slowed down neutrons and to absorb any gamma radiation accompanying the capture process (2).

Estimated data on the attenuation of neutrons is contained in Table XVI.

Table XVI. Neutron Attenuation Thicknesses (in.)

Material	Attenuation Factors				
	0.5	0.1	0.01	0.001	0.0001
Steel	3				
Concrete	4	10	20	30	40
Water		9			
Wet Soil		12	24	36	48
Soil		20			

The attenuation of fallout gamma radiation by any material is approximately proportional to the density of the material. The average energy of fallout gamma radiation is 0.7 Mev. The necessary thicknesses of various materials to attenuate gamma radiation of this energy by certain factors is contained in Table XVII (2).

Table XVII. Gamma Fallout Attenuation Thicknesses (in.)

Material	Density (lbs/cu ft)	Attenuation Factors				
		0.5	0.1	0.01	0.001	0.0001
Steel	490	1¼	3	5	7	9
Concrete	144	4½	10	17	23	28
Packed Soil	100	6	13	24	33	40
Timber	34	17	37	62	85	105

j. Fallout Shelters. A shelter may be designed purely for protection against fallout. In this case, the cover support would be designed to support the dead load of the cover only. Since a fallout situation may involve a shelter period of days, ventilation of the shelter becomes a critical problem.

For fallout protection, the quickest, cheapest, and most effective emergency measure is the covered trench. The trenches should be 4 ft to 6 ft deep and 2 ft to 3 ft wide. They should be covered with corrugated metal, timber, or any other material capable of supporting 2 to 3 ft of earth cover (40).

The attenuation factors for various structures are contained in Table XVIII.

An FCDA family-type shelter, Fig. 16, semi-buried, with 3 ft of cover and a closed entrance provides an attenuation of 0.0002 (17).

Table XVIII. Fallout Protection (43)

Protection	Attenuation Factor
Wooden shed	0.65
Wooden barn	0.50
Frame house	
Top floor	0.50
Ground floor	0.35
Basement	0.05 - 0.10
Brick house	
Ground floor	0.15
Basement	0.02 - 0.05
Subsurface	$<$0.01

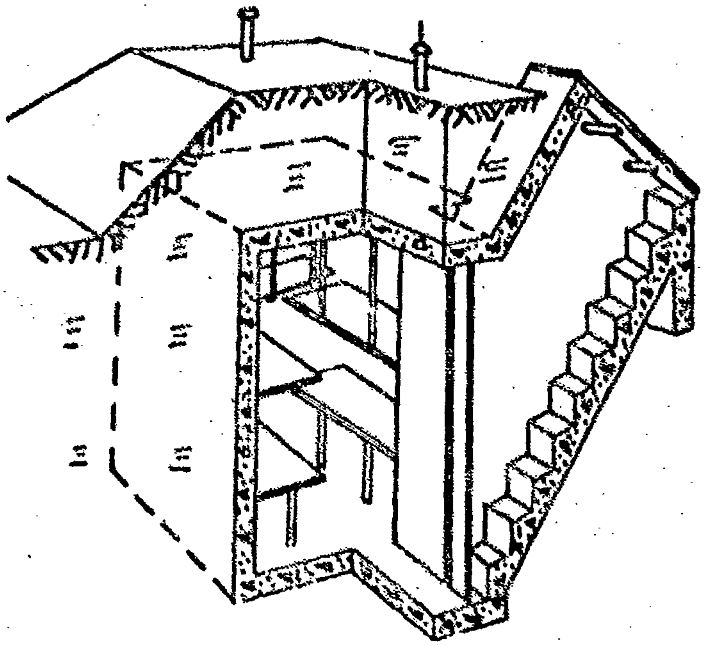


Fig. 16. FCDA shelter.

(C) During Operation TEAPOT, measurements were made on dummies exposed to a contaminating radiation field. Table XIX gives the results of these measurements.

Table XIX. Intensity of Fallout Within Shelters Exposed to a Contaminating Field

		Shelter Conditions			
Estimated Field Intensity	Dosimeter Type	Open Area	Wood Shack	Slit Trench	Slit trench with 3 ft earth cover
50-75 r/hr at 1 hour	Chemical	300r	150r	125r	
	DT-60/PD	415r	370r	250r	
50-75 r/hr at 1 hour	Chemical	300r		150r	small
	DT-60/PD	610r		260r	28r

These figures include prompt radiation doses and are for a 72-hour exposure to the contaminating field. (C)

(C) A test was made to determine the amount of shielding provided by field fortifications located in uniform fields of gamma radiation. Several types of field fortifications were constructed in a relatively smooth, grassy field and were then subjected to gamma radiation from cobalt-60 capsules distributed uniformly over the field. Attenuation factors for the various field fortifications as indicated by this test are as follows:

Prone shelter	0.05
One- or two-man foxhole	0.01
Trench	0.01
Horseshoe-type emplacement	0.01

These figures hold true only when there is no contamination within the fortification. If the fortification is contaminated, the interior dose will be about 50 percent of that outside. If kept uncontaminated, such fortifications will provide at least 80 percent to 90 percent protection at only 6 in. below ground level (44). (C)

(C) Sources of data (45, 46) on the military effects of fallout give attenuation factors for various field fortifications. These factors are for fighting emplacements; however, they would be conservative for shelters which would not have firing apertures. The attenuation factors are listed in Table XX. (C)

Table XX. Field Fortification Attenuation Factors against Fallout (C)

Fortification	Estimated Attenuation Factors Unmodified	Modified[c]
Foxhole[a], Open	0.08	0.02
Foxhole, $1\frac{1}{2}$ ft Earth Cover	0.003	0.002
Foxhole, $4\frac{1}{2}$ ft Earth Cover	0.0003	0.0002
Emplacement[b], 6' x 8', Open	0.25	0.10
Emplacement, 6' x 8', $1\frac{1}{2}$ ft Earth Cover	0.006	0.003
Emplacement, 6' x 8', $4\frac{1}{2}$ ft Earth Cover	0.0006	0.0003

(a) Minimum dimensions - 2' x $3\frac{1}{2}$', 4' deep

(b) Minimum depth - 4 ft

(c) Modifications - Increase depth to 6 ft, not including drainage sump. Place tarpaulin, shelter-half, etc. on a frame over open shelters.

Place spoil berm or sandbagging to height of 12 inches around perimeter of open shelter.

Extend cover overhang of covered shelter.

Place protective curtains over entrance.

An open trench 3 ft wide and 6 ft deep has an attenuation factor of 0.1 against fallout radiation (47).

k. Construction. Emergency shelters will be constructed by available mechanical and manual means. Mechanical equipment, if available, will make possible the most rapid construction of shelters. Equipment such as power shovels, dragline cranes, and backhoes could be used in construction of variable size shelters. These machines are very efficient in excavating and in placing earth cover or heavy shelter forms. Scrapers and dozers can be used for excavation of trenches although the large widths of the resulting trenches may be undesirable. For example, the blade width of dozers vary from about 6 ft for the small, 4-ton dozer to about 12 ft for the large, 28-ton dozer. A typical example of a dozer excavating a wide trench is shown in Fig. 17. A bulldozer is preferred over an angledozer. Scrapers are not an efficient piece of equipment for construction of shelters since they are designed for shallow cuts and medium to long hauls.

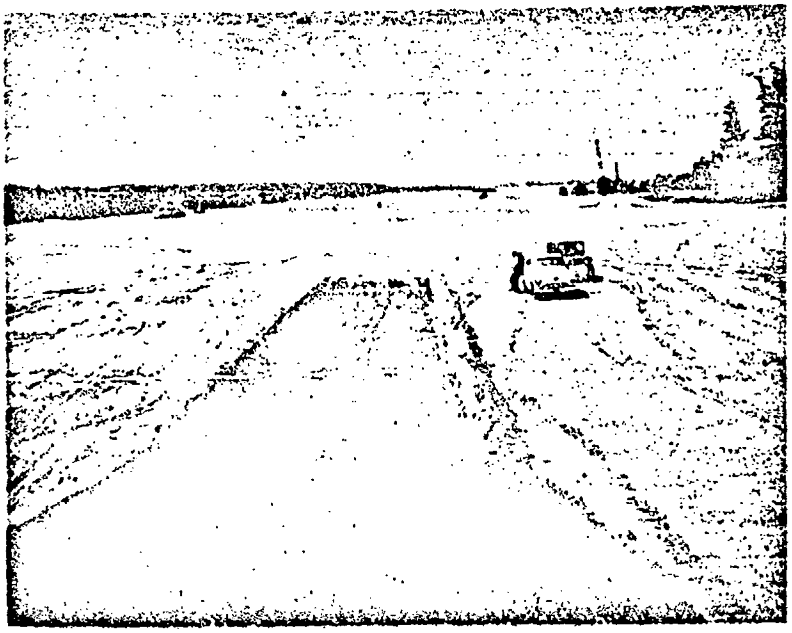


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Fig. 17. Dozer excavating a wide trench.

Mechanical trenchers are very efficient in the excavation of trenches. A military-type trencher is shown in operation in Fig. 18. A typical trench formed by this equipment is shown in Fig. 19. This trencher will form a trench, 2 ft wide and 6 ft deep, at the rate of 100 ft per 8 minutes in a non-rocky soil of reasonable consistency and strength. Commercial trenchers will excavate trenches of greater depth.

A truck-mounted earth auger is currently undergoing testing by the Corps of Engineers. This equipment is shown in the traveling position and in the drilling position in Figs. 20 and 21 respectively. It is capable of drilling holes 23 ft deep with diameters varying from 8 in. to 6 ft. A 42-in. diameter hole drilled by the auger is shown in Fig. 22. This equipment would only be of value where a number of small-capacity shelters would be desired.

1. Materials. Many structural materials, including steel, concrete, and wood, exhibit increased strength when subjected to rapid rates of strain such as would occur when the material is exposed to a blast wave. For high rates of loading, the yield point may be increased 50 percent or more over the value at low rates of loading. If ductile materials are used in blast-resistant design, it is possible and may be desirable for economic reasons to permit strains beyond the elastic limit (2).

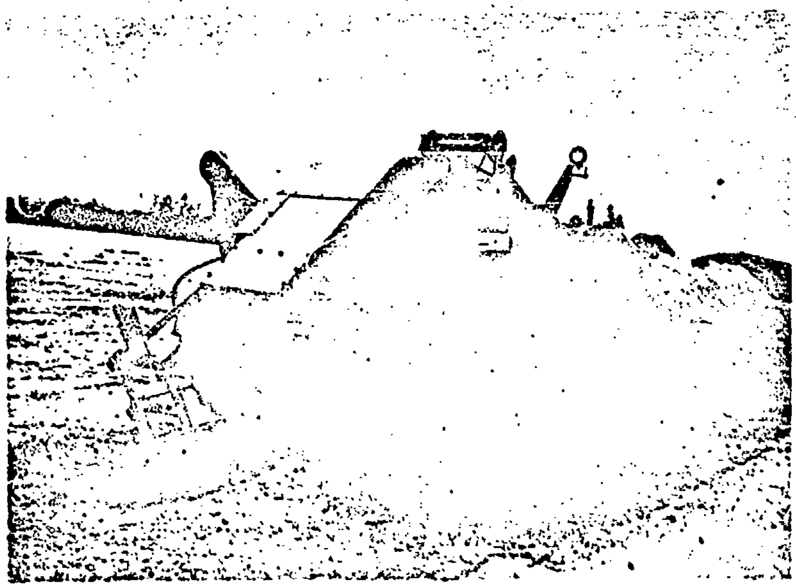

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Fig. 18. Trencher in operation.

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Fig. 19. Trench excavated by trencher.

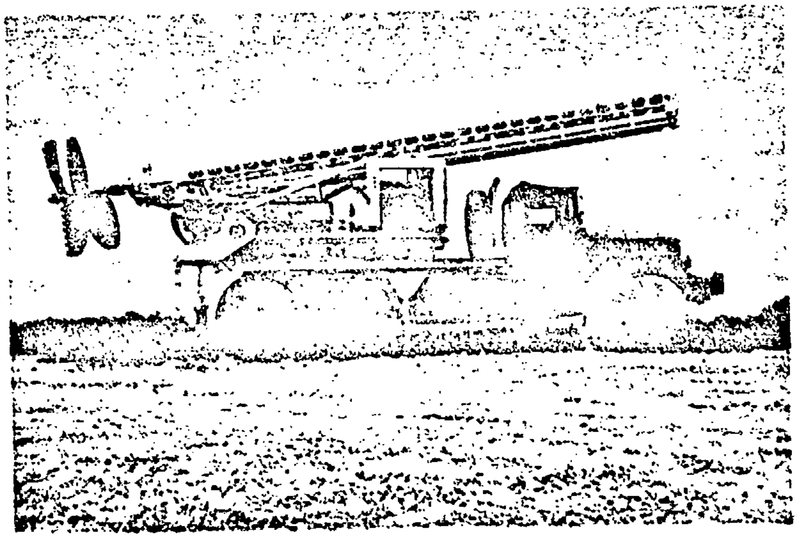

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Fig. 20. Mobile earth auger in traveling position.

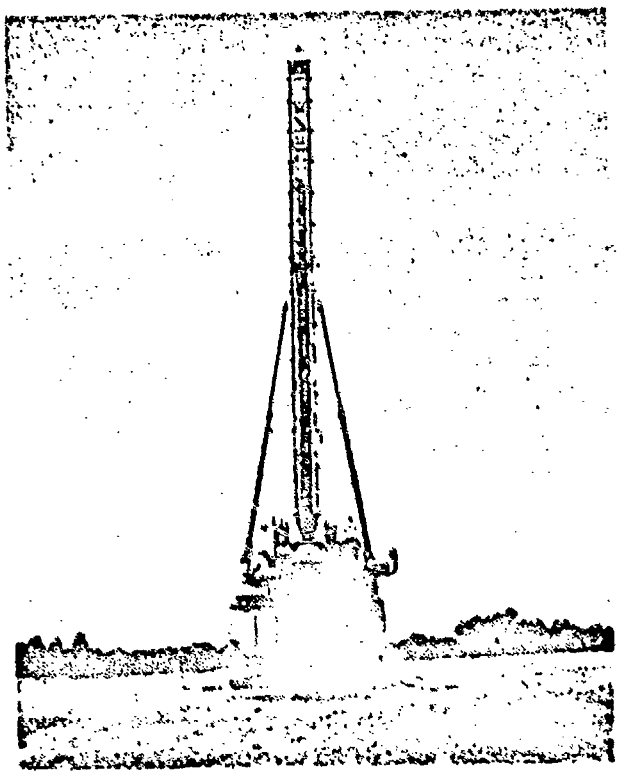

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Fig. 21. Mobile auger in drilling position.

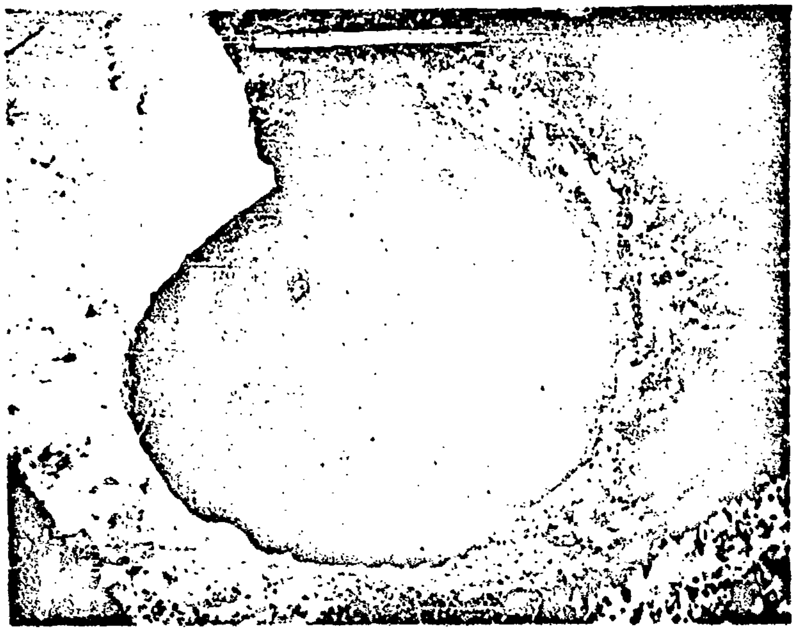

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Fig. 22. Auger hole, 42 in. dia.

Mass is important in blast-resistant design since as structural displacement takes place, the various masses undergo large accelerations. Other things being equal, a heavy structure will usually withstand the action of blast better than a structure that is less massive (2).

When structural materials are chosen, it should be borne in mind that the energy absorbed by a structure undergoing plastic deformation can make an important contribution to resistance to dynamic loading. Brittle materials, e. g., glass, cast iron, and unreinforced masonry, cannot tolerate strains beyond the elastic limit without suffering failure.

It is desirable in the construction of bearing walls, supporting floor, and roof systems to avoid the use of unreinforced brick, stone, or block since they are vulnerable to relatively low pressures acting transversely to the walls (2).

Metal and concrete pipe can be utilized efficiently for emergency shelters because a prefabricated cover support, revetment, and flooring are provided. Small pipe sizes can be used as a prefabricated entranceway.

Corrugated metal sheeting can be used as a cover support and as a revetting material providing it is adequately braced.

Wire screening and tarpaper can be used as a revetting material providing it is adequately braced. Tarpaper will furnish a certain amount of protection against soil moisture.

Corrugated metal pipe half-sections can be utilized as a cover support or a complete shelter support. Since this material is nestable, it can be efficiently stored. It requires fabrication but can be placed by hand.

Sandbags and masonry blocks can be used for revetment, but a certain amount of overexcavation is required if they are placed below ground. They are vulnerable to ground shock and air blast.

6. Shelter Types. The types of emergency or improvised shelters vary with the amount of effort and material required and the degree of protection desired. For the purposes of this report, the types of shelters will be divided into shelters furnishing minimum protection in the fastest time and those furnishing maximum protection consistent with available material.

a. Simple Shelters. These shelters are readily constructed with a limited amount of effort and expenditure of materials. They are effective against non-direct hits of H. E. weapons. They are limited in protection against nuclear weapons and ineffective against chemical and biological warfare agents.

(1) Prone Shelter. Prone shelters are used primarily in rear areas to protect men from bomb and shell fragments. They also protect against small arms fire. They are not as effective as foxholes. However, they can be dug quickly. The prone shelter is normally 2 ft wide and 2 ft deep. The length is slightly longer than the human body.

(2) Open Trench. Trenches should have a depth at least exceeding the height of a tall man, i. e., a minimum depth of 6 ft 6 in. Desirable widths should be 2 ft 6 in. at the bottom and 3 ft 9 in. at the top. However, the trench should be excavated to its maximum depth only for one-half of its width while the other half should be excavated 18 in. shallower. This will provide a ready-made bench to seat personnel.

In order to localize the effects of an exploding H. E. bomb, trenches should be made not straight, but either zigzag or traversed, with not more than 10 yd between angles and traverses. Lines of trenches should be spaced at least 15 yd apart (48).

In unstable soils, revetting of the trench walls will be necessary and it is desirable even in stable soils since

ground shock induced by blast may cause walls to collapse. This will necessitate overexcavating the trench in order to provide space for the revetting material. The open trench is effective against H. E. weapons except for direct hits and overhead air detonations. The protection against nuclear weapons is very limited.

(3) Foxhole. The foxhole serves as a combination shelter and fighting emplacement. Ordinarily, a foxhole is constructed in two sizes, one-man and two-man. Minimum dimensions are: width - 2 ft, depth - 4 ft, and length - 3.5 ft for one man and 6 ft for two men. The protection afforded by a foxhole is approximately equal to that afforded by a ditch. However, the construction time and cost per person sheltered is much greater for foxholes than for ditches.

(4) Covered Trench. The digging of trenches and provision of overhead cover is perhaps the easiest way to provide protection against most weapons (42).

Desirable dimensions are the same as for the open trench even when the cover support is placed below the ground surface. In this case, the whole trench is placed at the depth necessary to maintain the interior height of 6 ft 6 in. minimum.

Against H. E. weapons, trenches provided with overhead cover are equal in protective value to underground dugouts and galleries with the same depth of overhead cover (48).

The covered trench is very effective against nuclear weapons. Its open entrance is the only apparent weakness against nuclear weapons when blast becomes critical.

Beams utilized for the cover support should be at least three times the top width of the trench in order to provide sufficient bearing area on the sides of the trench to prevent collapse of the trench walls.

The cover over a covered trench consists of 3 ft minimum of earth and a simple beam type of cover support. Wooden logs or beams would be suitable. This material would be supported by the earth sides of the trench.

b. Special Shelters. Special shelters require considerably more effort and expenditure of materials than do simple shelters. They will, of course, furnish greater protection than the simple shelters. The design problem is quite difficult and varies considerably with the elevation of the shelter itself. For this

reason, the design of special shelters has been considered according to the relationship between the shelter and the original ground surface.

(1) Surface Shelters. Surface shelters are situated entirely above the surface of the ground.

Surface shelters are built only when ground conditions prohibit construction of underground shelters and when the situation permits expenditure of the necessary time and labor (30).

The advantages of surface shelters are: they are adaptable to unfavorable soil conditions; they are readily accessible and may be evacuated quickly through an emergency exit; the degree of protection may be increased by adding sandbags or earth-filled timber cribs to exterior surfaces; they are not exposed to intense earth shock from bombs exploding in earth (1).

The disadvantages of surface shelters are: they are subject to drag forces from nuclear weapons; they require a large quantity of earth cover as part of their protection; the entrances are particularly vulnerable to nuclear weapons; stability of the structure requires a certain amount of continuity between roof, walls, and floor.

(2) Buried Shelters. Buried shelters, including their earth cover, are entirely below the surface of the ground. This is the most effective design. It will give the greatest protection of the three designs considered here.

Elevation of the ground water table will have important bearing on the question of whether a buried shelter will be used. Construction details of improvised shelters probably will not include waterproofing of the interior of the shelter.

Revetment will probably be one of the main problems unless a pipe section is used for a shelter.

(3) Semi-Buried Shelters. Semi-buried shelters project partly below and partly above the ground surface. This is probably the most widespread design to be utilized because of savings in time and material. This design is efficient in protection and economical in expenditure of time and material. It usually would require less construction than either of the other special shelters primarily because the buried shelter would require greater excavation and the surface shelter would require

excavation from a borrow pit for its earth cover while the excavation for the semi-buried shelter furnishes the necessary earth cover.

Placing of this structural design so that the cover support, if flat, would rest just below the ground surface would eliminate drag loading on any part of the shelter except the earth cover. Drag loading will be quite severe on any portion of the shelter that protrudes above grade.

7. Atomic Test Shelters. Following are descriptions of the effects of atomic weapons on personnel shelters. Emergency-type shelters and other types of shelters which may contain data of value in the design of emergency shelters are included.

(C) A type of outdoor family shelter was tested during Operation TEAPOT. It was an above-ground, utility-type shelter, Fig. 23, which could be used as a tool shed when not needed as a shelter. The inside floor dimensions were 6 by 6 ft, and the interior was 7 ft high. All walls except the one with the door were 6 in. thick. The wall with the door was 8 in. thick. The outside shelters were constructed of masonry block, precast reinforced

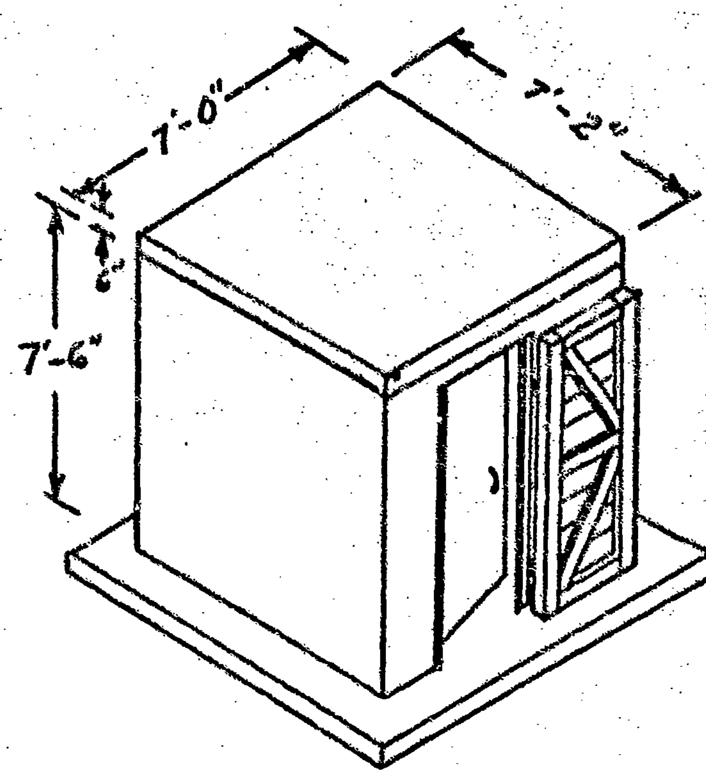


Fig. 23. Outdoor family shelter-utility shed.

concrete, or poured-in-place reinforced concrete. One of each of the three types was tested at three different pressure levels. The three types of outside shelters were subjected to the effects of a 30-KT weapon on a 500-ft tower at distances of 2250, 2750, and 3750 ft. These utility shelters failed at 12 psi. Those at the farthest distance would have been dangerous for occupants because of failure of the interior door. The utility shelters did not reduce radiation doses to an acceptable level. Fastening of the interior doors in an open position would have eliminated the missile hazard to occupants. Since a shelter's design criteria should be based on the effects of any probable weapon and in view of high-level fallout radiation from high-yield weapons, it was recommended that the concept of an above-ground shelter of this type be dropped unless the shelter is redesigned to include a large amount of overhead earth cover and a radiation baffled entrance (35). (C)

(C) Underground personnel shelters, Fig. 9, which were capable of accommodating 50 persons were also tested during Operation TEAPOT. These shelters were of reinforced concrete and included a stairway entrance with two 90-degree bends and also an escape hatch. The entranceway included a blast-resistant door into the shelter proper and a horizontal blast-resistant sliding door at the ground surface. With the entrance and hatch closed, there was no damage from 47 and 92 psi or from thermal effects. The earth cover was 5 ft 6 in. deep. Attenuation of gamma radiation was great. Eight-thousand-five-hundred roentgens just below the sliding door was attenuated to less than 1r within the shelter proper. On another shot, 25,500r just inside the sliding door was attenuated to 1 to 2r within the shelter proper. For the initial shot, 2.87×10^{11} fast neutrons/cm^2 at the surface was attenuated to 1.72×10^8 neutrons/cm^2. There was no measurement of slow neutrons. The fast neutron radiation inside was equivalent to 109 roentgen equivalent man (rem). For the later shot, 1.53×10^{12} fast neutrons/cm at the surface was attenuated to 4.01×10^8 neutrons/cm^2. A slow neutron surface intensity of 3×10^{13} slow neutrons/cm^2 was attenuated to 2.33×10^8 neutrons/cm^2. The fast and slow neutron interior doses were equivalent to 256 rem and 19 rem, respectively (35). (C)

(C) Shelters of the same design, Fig. 9, were also tested with the doors and escape hatches open but partially obstructed to meter air into the chambers slowly. The shelter was divided into two chambers by a reinforced concrete wall. The chamber into which the escape hatch entered was referred to as the "slow-fill" room, and the other chamber was referred to as the "fast-fill" room. Gamma radiation measurements were higher than in the closed shelters. The radiation intensity at the first 90-degree bend in the entrance was 16 times as great as it was in the closed shelter for the initial shot. The reduction must be attributed to the shielding afforded by the concrete sliding door that was used to seal the structure. Even

though the entranceway was open, it was effective in reducing gamma radiation to a general level of about 25 to 35r in the fast-fill chamber. The area directly under a ventilation pipe received about 110r which can be attributed to radiation scatter at the pipe. The intensity of gamma radiation in the slow-fill side varied from a high of about 530r directly under the escape hatch opening to 65r at the diagonally opposite corner. The radiation gradient in this chamber plus the generally higher level of radiation when compared with the fast-fill chamber can be attributed to the amount of radiation scatter from the escape hatch opening. The second shot involved a higher gamma intensity. The intensity at the first 90-degree bend in the entrance was three times as great as it was for the initial shot. The dose within both chambers was twice as great as it was for the initial shot. The fast neutron dose within the fast-fill chamber was 4 times as large as it was in the closed shelter for the initial shot. The total neutron dose for the later shot in the open shelter as compared with the closed shelter was 4 times and 12 times as large for the fast-fill and slow-fill chambers, respectively. Thermal effects within both chambers from both shots were limited. The fur of experimental animals was singed only. Thermal energy within the shelters was apparently heated air rather than reflected thermal rays. The measured peak temperatures varied from 150 to 350 C, but the duration was very short. The large ratio of interior cross-section to doorway or hatch aperture caused a rapid cooling of the heated air. The surface overpressure of 47 psi from the initial shot was reduced to 26 to 37 psi within the fast-fill chamber and 2 to 7 psi within the slow-fill chamber. The surface overpressure of 92 psi from the second shot was reduced to 64 to 74 psi within the fast-fill chamber and 22 psi within the slow-fill chamber (35). (C)

(C) Comparison tests were conducted on covered and uncovered trench shelters, Fig. 5, at Operation TUMBLER. The trenches were "Z" shaped with the middle or main portion being 25 to 30 ft long and 24 to 26 in. wide. The arms of the shelters were the entrances and varied from 8 to 11 ft in length and were dug to a depth of 2 ft at their outer edge and sloped to the level of the floor of the main trench. The depths of the main portion varied from 5 to 6 ft. The covered trenches were covered by 2 ft of earth which was supported by 2- by 12-in. wood planking that overlapped the sides of the trench by at least 2 ft. Different shapes of the cover were provided for comparative purposes. The trenches were constructed at various distances from ground zero. The weapon was the nominal or 20 KT. Protection against gamma radiation varied considerably with distance, e. g., the attenuation factor for the covered shelter, 3 ft above the floor, was 0.14 at 625 ft from ground zero while that at 4925 ft was 0.012. Attenuation factors for the uncovered trench at 3 ft from the bottom were 0.18 and 0.07 for 625 and 4925 ft, respectively. In comparison with the 3-ft level in the covered trench, attenuation at the 18-in. level was 50 to 100 percent greater, i. e.

0.09 and 0.0067 at 625 and 4925 ft, respectively. Test results showed that the earth mound forming the cover should be shaped broad and flat. The peaked mound of the covered shelter at one position was greatly lowered while the flat, low mound formed from the spoil of the uncovered shelter at that position was only slightly altered by the blast. Test results indicated that the 2- by 12-in. cover support was capable of withstanding 15 psi overpressure. No measurements were made of thermal radiation, but it was estimated that the thermal effects within the shelters were negligible (28). (C)

(C) Tests were conducted during Operation BUSTER to evaluate the protection afforded by foxhole-type field fortifications against the nuclear radiation from atomic weapons. Standard foxholes, as described in FM 5-15 (30), provide considerable protection from the nuclear radiations emitted during an atomic detonation. The standard two-man foxhole will receive only one-eighth the amount of gamma radiation at the bottom as received at the top of the foxhole (49). (C)

(C) Three types of communal shelters were tested during Operation UPSHOT-KNOTHOLE. Shelter 601, Fig. 8, consisted of a 48-ft concrete pipe 90-in. I. D., buried 3 ft with one end closed; the entrance was from a single ramp parallel to the axis of the pipe. Shelter 602, Fig. 7, consisted of one 24-ft section of 90-in. I. D. corrugated metal pipe and one 24-ft section of 90-in. I. D. concrete pipe, buried 3 ft with one end closed; the entrance was from a double ramp parallel to the axis of the shelter. Shelter 613, Fig. 24, consisted of a 12-ft section of 90-in. I. D. steel pipe placed above ground, covered with 3 ft of sandbags and mounded earth (34). (C)

(C) Shelters 601 and 602 were subjected to the effects of an 18-KT weapon at 1500 ft. The measurements inside the shelters gave attenuation factors of 0.0005 and 0.0001 for gamma rays and neutrons, respectively. The exterior gamma dose was 17,000r. Dosages near the doorways were higher than those within the balance of the shelters and were considered to be due to scattering from the entranceways (34). (C)

(C) All three shelters were subjected to the effects of a 32-KT weapon. Shelters 601 and 613 were 2300 ft from ground zero, while shelter 602 was 2600 ft from ground zero. Gamma radiation within 601 and 602 was very near the minimum measurable level, so the attenuation factor of 0.0002 may not be reliable. Attenuation factors from these shots are not believed to be truly representative of a situation where the shelters would be located close to ground zero under an air burst. It is believed that under these conditions, the gamma attenuation factor would be of the order of 0.005 rather than the 0.001 observed during these tests. Gamma radiation within shelter 613 ranged from 1600r in the closed end to 3400r near the

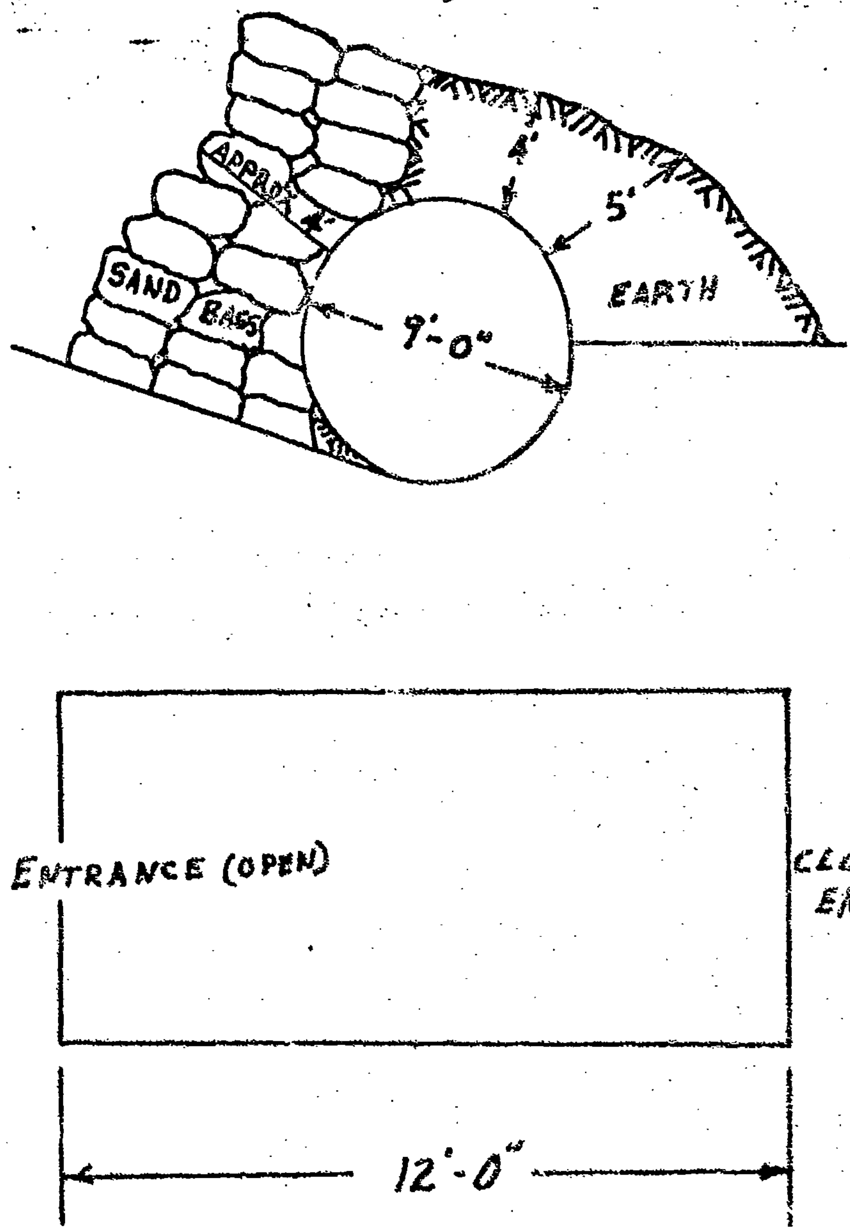


Fig. 24. Shelter 613

open end of the shelter. The attenuation factor was only 0.1. It is believed that the sandbags not only leaked radiation but that they were partly destroyed by heat and blast before an appreciable fraction of the total radiation dose had been delivered (34). (C)

(C) Another shelter was tested during UPSHOT-KNOTHOLE against the effects of a 60-KT weapon at a slant distance of 1800 ft. This shelter was similar to shelter 602, i. e., it consisted of a 24-ft section of 90-in. I. D. corrugated metal pipe and a 24-ft section of 90-in. I. D. concrete pipe, buried 3 ft with one end closed; the entrance was from a double ramp perpendicular to the axis of the shelter. The essential difference between the two shelters is the orientation of the entranceways. The gamma dose within the shelter varied from 250 to 3000r, the highest near the entrance. The attenuation factor varied from 0.00167 to 0.02. The attenuation factor for neutrons was 0.00545 with an internal dose of 3×10^9 neutron/sq cm (15). (C)

(C) During Operation BUSTER, the AEC conducted a test of a communal shelter. The structure, Fig. 4, was made of 90-in. I. D. pipe, 48 ft long. Half was concrete pipe, reinforced, centrifugally cast, 7-3/4 in. thick; and half was corrugated iron, 10-gauge, ingot iron multiplate. Each end opened into a double ramp, reinforced concrete adjoining the concrete pipe and steel adjoining the iron pipe. The steel ramp was made of 10- and 12-gauge corrugated sheet and structural steel. Earth cover was 3 ft thick over the concrete pipe and 3 ft 8 in. over the steel pipe, mounded about 2 ft above grade and sloped about 1 in 10. The test shot delivered 9 psi and 13,000r to the shelter at ground level. Damage to the shelter from blast pressure was negligible. It consisted of a permanent deflection downward of less than 1 in. Minor tension cracks developed in the joints and the top and bottom of the concrete pipe. No damage was observed in the metal pipe sections. The measured intensity of gamma radiation at the center of the shelter was 73r. Some of this was possibly due to scattering through the entrances. Even though thermal energy at the surface was 60 cal/sq cm, there was no evidence of thermal effects on five pieces of lumber distributed along the axis of the shelter floor (22). (C)

(C) The second shot delivered 24 psi and 35,000 roentgens to the shelter at ground level. Damage to the shelter from blast pressure was again negligible except for removal of a considerable amount of earth cover. The measured intensity of gamma radiation at the center of the shelter was 260r. Some of this was possibly due to scattering through the entrances. Thermal energy at the site was 160 cal/sq cm (22). (C)

(C) The third shot delivered 25 psi and 70,000r to the shelter at ground level. Damage to the shelter proper was light, consisting of further settlement and enlargement of the existing cracks and joints. The mounded earth cover was removed entirely by the blast wave, and the site was leveled. The ramp entrances were heavily damaged. Earth swept into the ramps by previous shots and occupying 20 to 30 percent of the shelter entrance opening caused

lower pressures inside the shelter in comparison with those from the second shot. The measured intensity of gamma radiation at the center of the shelter was 375r. Thermal energy at the site was 220 cal/sq cm. A wood plate between the top of the displacement gauge and the concrete pipe was charred, but a similar wood plate used with the displacement gauge in the metal pipe was not charred (22). (C)

(C) Gamma measurements indicated the effectiveness of the shielding materials. The slant path through the materials consolidated around the circular shape gave obvious shielding advantages over a flat shelter roof with cover of uniform thickness. The increase in intensity of radiation near the open ends, however, clearly dictated the need for baffling or shielding against scatter-radiation. The observed thermal effects inside the shelter following the second and third shots were unexpected. However, no measurements were made, and the possible effects on occupants are unknown. The shelter provided structural resistance against physical damage from overpressures and, it is believed, against wind drag. Reflected pressures, varying from 25 to 45 psi, within the shelter were always larger than surface overpressures. Dynamic pressures within the shelter caused small movements of dummies made of burlap bags, sawdust, and soil (22). (C)

(C) At Operation RANGER, a number of foxholes were tested for effectiveness against gamma radiation. There were three types of foxholes tested: a prone shelter, one-man foxhole, and two-man foxhole. The prone shelter was 2 ft deep, and the foxholes were 4 ft deep. Gamma measurements were at 12-in. and 24-in. depths in the prone shelter and at 16-in., 32-in., and 48-in. depths in the foxholes. The test shots were 1-, 7-, and 22-KT weapons exploded at 2000-ft altitude. The measurements gave variable results. The doses at 48 inches in the two-man foxholes were as follows: 400 yd from ground zero, 3 to 18% of the surface dose; 800 yd, 10 to 22%; 1200 yd, 10 to 11%; 1600 yd, 12 to 23%; 2000 yd, 11%. The doses at 32 inches in the two-man foxholes were as follows: 400 yd, 7 to 14%; 800 yd, 7 to 24%; 1200 yd, 9 to 17%; 1600 yd, 14 to 25%; 2000 yd, 15%. The doses at 16 inches in the two-man foxholes were as follows: 400 yd, 5%; 800 yd, 16%; 1200 yd, 5 to 29%; 1600 yd, 17 to 20%; 2000 yd, 19%. Doses within the prone shelters were similar to those within the two-man foxholes, i. e., the doses at 12-inch and 24-inch depths in the prone shelter were, respectively, slightly greater and slightly smaller than the doses at the 16-inch depth in the two-man foxhole (50). (C)

III. DISCUSSION

8. Weapons Effects. An evaluation of the effects of weapons will be made, and a critical level for each effect will be brought out.

a. H. E. Weapons. It is apparent that in the design of improvised shelters, it is both unnecessary and uneconomical to provide bomb-resistant protection against H. E. weapons. These shelters would not be of strategic importance. They would not be operations posts; therefore, the loss of any one shelter would not cause a complete operational breakdown. Providing protection against blast and fragmentation from a near miss of a specified bomb should be adequate. This amount of protection would be effective against direct hits of small artillery shells and small aerial bombs such as incendiaries. The thicknesses of various materials necessary for protection against blast and fragmentation as specified in the investigation section, Table IX, is an acceptable design level. If an earth cover is included, a shelter designed for atomic blast would possibly be able to absorb the effects of direct hits of medium-size, e. g., 105-mm, H. E. shells.

b. Nuclear Weapons.

(1) Blast. Drag forces are of such overriding importance as to demand that shelters be either placed below ground level or streamlined with soil sloped no more than one in two. Assuming such provision for drag forces, then peak overpressure is the design problem. Open shelters need not be designed to withstand pressure above that which a human can withstand. The range of such pressure is highly controversial. However, it is estimated that 35 psi or more is required for internal physical damage due to crushing. Eardrum rupture pressure is estimated as being about 20 psi. Hence, design pressure for an open shelter need not exceed 30 psi. Protection against higher pressures will demand a closed shelter; this would involve a fundamental change in design.

Cost data for different levels of blast protection suggest the following relative figures for a 100-person shelter: 10-psi blast protection, \$30 per person; 25-psi blast protection, \$55 per person; 100-psi blast protection, \$330 per person. The data suggest that if blast protection above 25 psi is desired, it is wiser to design for 100 psi than to accept, say, 50 psi. These figures are based on the 1957 dollar (29).

(2) Thermal. The intensity of thermal radiation for design purposes is rather indefinite. The amount of thermal energy reflected by a soil is estimated to vary from a negligible quantity to as much as 15 percent. If this maximum figure is correct, personnel in foxholes or open trenches would be safe only against a maximum intensity of 20 cal/cm^2 which would cause first-degree burns on unprotected parts of the body. If the negligible quantity is correct, personnel in foxholes or open trenches would be safe against as much as 200 cal/cm^2.

The correct figure for reflectance is probably between the two extremes but nearer to the negligible quantity. Assuming acceptable injury as first-degree burns equivalent to a mild sunburn, then the design level for open shelters would be about 100 cal/cm^2. The scattering which occurs on slightly hazy days may make this figure too high.

If the entrance is oriented so that no direct thermal radiation enters it, the amount of thermal energy received in a covered shelter will be negligible. If the entrance faces the detonation, two turns in the entrance will be sufficient to reduce reflected radiation to a negligible amount except in those cases where outside thermal energies of several thousand calories per sq cm occur. However, in many instances, heated air will be driven into shelters by the blast wave. This heated air may attain a temperature of several hundred degrees centigrade but will be of short duration.

(3) Gamma Rays. The permissible interior intensity of gamma radiation is somewhat indefinite. It could vary from less than 1r to a probable maximum of 100r. The FCDA and AEC shelter tests indicate a desire to limit interior dose to less than 10r. For military personnel, a higher dose level is probably acceptable. Permissible interior intensity of gamma radiation will be discussed further in a succeeding paragraph where multiple prompt effects will be considered. Examination of shelter tests show that, except for overhead bursts, a structure buried 3 ft and incorporating proper entrance design will attenuate gamma radiation by factors varying from 0.001 to 0.00(

(4) Neutrons. The permissible intensity of neutron radiation is indefinite. Apparently, the intensity of neutrons is equal to or greater than the gamma intensity for weapons of 25 KT or less. This will be covered further in a succeeding paragraph where multiple prompt effects will be considered. Examination of shelter tests show that, except possibly for close-in bursts, a structure buried 3 ft and incorporating proper entrance design and orientation will attenuate neutron radiation by factors varying from 0.005 to 0.0001. However, attenuation factors for total neutron doses were given in only two instances, and in these instances, the attenuation of neutrons was 1/3 to 1/5 the attenuation of gamma rays. One thing that should not be forgotten is that whatever the acceptable nuclear radiation dose, it has to include the total of neutrons and gamma rays. The chemical composition of the earth cover is critical as regards attenuation of neutrons.

(5) Multiple Prompt Nuclear Effects. In designing against prompt nuclear weapons effects, it is obvious that the

effects have to be considered in multiple. A comparison of the various radiation effects from various size weapons for three levels of overpressures have been made in Tables XXI and XXII. The initial table considers effects from typical air bursts which cause maximum blast damage, while the second table considers surface bursts which cause maximum radiation damage. These two extremes show widely separated effect intensities. A large city would be a likely target for a typical air burst, while a small target would be most likely hit with a surface burst since blast effects at great distances are not necessary. Examination of Table XXII for surface bursts shows that for 30-psi blast pressure, radiation totals are quite critical up to 100-KT weapons. At the 10-psi level, the neutron dose is critical up to 50-KT. Above this size, the blast loading becomes critical. However, surface bursts of large nuclear weapons are not likely to occur except when fallout is the desired effect. At the 20-psi level, there is somewhat of a balance between blast effects and radiation effects. Thermal energies are critical only in the megaton range. Examination of Table XXI for typical air bursts shows that blast is the critical effect for weapons in the megaton range. None of the other effects in the megaton range are important with the possible exception of thermal energy. Neutron intensity is high over all three overpressure ranges for the small weapons, 25 KT or less. At the 20- and 30-psi level, neutron intensity is also important for 50- and 100-KT weapons. Only when the weapon size varies from 100 KT to 1 MT does gamma radiation become important and even then only at high overpressures.

Obviously, in designing a shelter against prompt nuclear effects, a decision has to be made as to a probability of weapon size, height of detonation, and expected ground zero. If the personnel to be sheltered are located on the outskirts of a large city, then the nuclear weapon will probably be a large one detonated at optimum blast height. If the personnel are located at a small base or installation, then the weapon will be in the small-to-medium range probably at or close to the ground surface. This again brings up the problem of acceptable dose. If 100 rem is acceptable, then a buried shelter could protect against a minimum of 20,000 rem of neutron or 60,000r of gamma rays or a combination of both. If 1r is a maximum acceptable dose, then probably a buried shelter would protect against a maximum intensity of 10,000 rem of neutrons or 30,000r of gamma rays or a combination of both. According to the table for surface bursts (XXII), the nuclear radiation at the 30-psi level is too great to be attenuated for 50-KT or less-size weapons unless 100 rem is an acceptable dose. A look at the table for typical air bursts (XXI) shows that attenuation of nuclear radiation is possible for all size weapons even when

Table XXI. Intensities of Nuclear and Thermal Radiation at Various Overpressure Levels for Various Size Weapons (Typical Air Bursts)

Weapon	10 psi overpressure				20 psi overpressure				30 psi overpressure			
	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)
1KT	1500	4800	6300	15	6,000	18,000	24,000	35	8,000	25,000	33,000	50
10KT	600	1000	1600	29	4,500	12,000	16,500	70	6,300	20,000	26,300	90
25KT	300	290	590	35	3,000	5,500	8,500	100	5,000	11,250	16,250	115
50KT	160	70	230	45	2,100	2,600	4,700	120	3,800	5,500	9,300	140
100KT	60	15	75	52	1,400	900	2,300	150	2,600	2,100	4,700	160
1MT	neg	neg	neg	107	85	neg	85	300	260	10	270	320
10MT	neg	neg	neg	180	neg	neg	neg	350	neg	neg	neg	570

Note: Data incorporated into this table was computed from data available in reference (2).

A typical air burst height for a 20-KT weapon was assumed to be 2,150 ft. Using this assumption, typical air bursts for the other weapons were computed as the heights vary directly as the cube root of the weapon powers.

$$\frac{\sqrt[3]{20KT}}{\sqrt[3]{1KT}} = \frac{Ht_{20KT}}{Ht_{1KT}}$$

Table XXII. Intensities of Nuclear and Thermal Radiation at Various Overpressure Levels for Various Size Weapons (Surface Bursts)

Weapon	10 psi overpressure				20 psi overpressure				30 psi overpressure			
	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)	gamma (r)	neutron (rem)	total nuclear (rem)	thermal (cal/cm²)
1KT	5200	15,000	20,200	32	12,500	35,000	47,500	70	25,000	60,000	85,000	100
10KT	3400	9,000	12,400	64	13,500	39,000	52,500	25	28,000	80,000	108,000	200
25KT	2430	4,000	6,430	80	10,600	26,000	36,600	75	23,000	62,500	85,500	250
50KT	1570	1,650	3,220	95	8,800	17,000	25,800	200	20,200	47,000	67,200	335
100KT	900	530	1,230	110	6,750	7,300	14,050	230	19,500	28,000	47,500	400
1MT	50	neg	50	220	1,300	80	1,380	450	6,500	700	7,200	700
10MT	neg	neg	neg	400	25	neg	25	880	200	neg	200	1400

Note: Data incorporated into this table was computed from data in reference (2).

a low allowable dose is necessary. These data demonstrate that no flat intensity figures for design purposes can be stated. An examination of the situation has to be made, and toleration limits of blast and nuclear radiation have to be established also. If weapons which cause high neutron yield are considered, then the attenuating ability of the shelter has to be increased.

(6) Fallout. Examination of the data on fallout shelters discloses that a semi-buried shelter with a closed or filtered entrance will attenuate fallout gamma energy by a factor of 0.0002. A buried shelter would be even more effective. Fallout intensity is difficult to predict because of such variables as weapon size, type of weapon, distance away, wind direction, and wind velocity. The intensity of fallout varies with time. One source (2) states that fallout decays at a rate so that at the end of one hour, 56 percent of the infinity dose has been received. Assuming an allowable total dose of 125r of fallout gamma, then a buried fallout shelter could easily protect against a fallout intensity of 650,000r/hr at 1 hr. This intensity is, of course, extremely high. Such a buried fallout shelter will protect against surface bursts of megaton weapons (2). In short, buried shelters can be designed that will protect against any anticipated level of fallout.

c. Chemical Warfare Agents. Since mechanical ventilation for emergency shelters will not usually be provided, the protection which they can afford against war gases is limited. Closure of vents and entrances with protective curtains which will provide filtered ventilation will suffice for a short time. However, these filtration curtains will reduce freshening of the air in the shelter and will limit habitation time. Against gases which are dangerous only if inhaled, it will not be necessary to filter air through the entrances if personnel are provided with the protective gas mask. The gas mask would be sufficient against inhalation gases except in instances of very high concentrations. If the gases encountered are of the blister, blood, or nerve type, protective clothing will also be necessary.

If the shelter is provided with mechanical, filtered ventilation, then the only necessary requirement is that a sufficient rate of intake be maintained to provide a positive interior pressure. For shelters without mechanical ventilation, the minimum concentration to be considered would require protective curtains over the entrances. It would probably be desirable to consider strong intensities of reasonable lengths of time which would require gas masks and protective clothing.

d. Biological Warfare Agents. The problem involved here is very similar to the one involving gas warfare. For shelters without mechanical ventilation, the minimum intensity to be considered

would require protective curtains over the entrances. It would probably be desirable to consider intensities of such lengths of time that protective masks and protective clothing may be required. If the shelter is provided with mechanical, filtered ventilation, then the only necessary requirement is that a sufficient rate of intake be maintained to provide a positive interior pressure.

9. Shelter Design Components. An evaluation will be made of each item considered pertinent in the investigation section.

a. Earth Cover. Test results definitely show the value of earth cover. The many advantages of earth cover over shelters far outweigh costs of excavation and placement. Among these advantages are: structural mass increase, absorption of blast energy, attenuation of nuclear radiation, protection against fragmentation, modification of aerodynamic shape of the structure, and buttressing effect. The increase in mass is important for short-duration loads. However, for long-duration loadings, it apparently is not significant. There is considerable reduction of drag forces on the sides of a structure when the earth cover is gradually sloped. Proper placement of soil will modify the aerodynamic shape of the structure and will tend to prevent removal of the cover by drag forces. For this purpose, side slopes of the earth cover should be very gradual, probably no greater than 30 degrees; otherwise, large quantities of cover may be removed by the blast wave exposing the shelter to nuclear radiation. It is important to remember that attenuation figures are given for compacted earth. Uncompacted covers may require as much as 50 percent greater thicknesses for radiation protection. A compacted cover is more stable and less subject to wind removal.

To sum up, earth cover should have sufficient thickness for nuclear radiation attenuation and gradual side slopes for reduction of blast effects. The ideal streamlined form of earth cover would be smooth and level with the surrounding ground surface with the shelter completely buried. The usual design may compromise this feature because of other factors such as water table or cost of excavation. Other things such as borax and water for neutron attenuation may be considered.

b. Cover Support. There are no data for correlating dynamic blast loading and equivalent static loading for design of emergency shelters. For this reason, precise design procedure is not now possible. Nevertheless, it is possible to make a few simplifying assumptions and arrive at a practical design procedure that will satisfy most requirements and still afford efficient use of materials.

In this respect, it is helpful to note that radiation will dictate massive earth cover as a practical feature for attenuation. This much of the load on structural elements is, therefore,

predictable. Massive cover will make the structure slow to respond to blast loads. Thus, for open shelters designed to withstand no more than 30-psi overpressure, it is safe to assume that internal pressure will rise to equalize external pressure before the structure can move sufficiently to develop the full load of blast. It is safe, therefore, to design such a structure to support its earth cover as a load dropped from zero height; that is, with a dynamic load factor of only two.

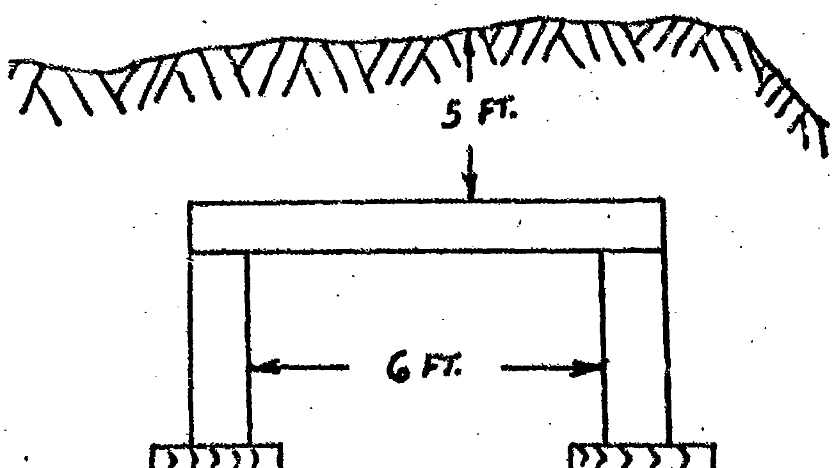
Closed shelters present another problem. This same procedure would be acceptable for closed shelters if only short-duration pressure pulses were considered (one quarter second). Megaton weapons produce blast pressure pulses of long duration. In case of attack by a megaton weapon, the pulse of blast pressure will be of such duration that inertia of the earth cover will be overcome. Structural elements will be subjected to the full load of peak overpressure, plus static load of the earth cover, plus dynamic load imposed by movement of the cover (dynamic load factor of two). Although this over-simplified approach ignores many factors affecting blast load on a structure, it will afford safe designs with reasonable efficiency in use of materials.

An emergency shelter that would develop plastic failure without collapse would be ideal in that it would represent most efficient use of structural elements.

An example of a design detail based on the foregoing assumptions follows.

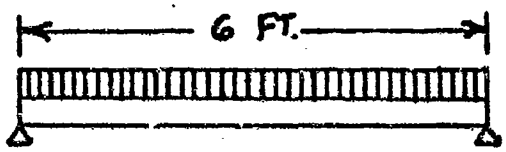
(1) Example Calculation of Roof Timbers for an Open Structure.

Given: An open shelter with a roof span of 6 ft. Radiation and other factors require cover of 5 ft of uncompacted $70\#/ft^3$ soil. Overpressure reaches a maximum of 30 psi.



Problem: Design roof stringers.

Solution: For an open structure, the static load condition is usually critical, since pressure waves can enter an open shelter and somewhat cancel out the full effect of overpressure. For the dynamic load condition, use a dynamic load factor of two. Consider a section of roof 1 ft wide and 6 ft long. Treat this as a simply supported, uniformly loaded beam.



Case I: static load

w = load per inch of beam

$= 5' \times 1' \times 70\#/ft^3 \div 12 \text{ in/ft} = 29.2\#/\text{in.}$

$S = M \frac{c}{I}$ S = working stress (Table XXIII)
M = maximum bending moment
c = beam thickness (h) ÷ 2
I = moment of inertia
l = length of beam

$$M = \frac{wl^2}{8} = \frac{29.2(72)^2}{8}$$

$$M = 18900''\#$$

$$I = \frac{bh^3}{12} = \frac{12\,h^3}{12} = h^3$$

b = beam width,

h = beam height

S = 1750 psi for southern yellow pine   See Table XXIII

$$1750 = \frac{18900\,h}{h^3\ \ 2}\ ; \qquad h^2 = \frac{18900}{1750(2)}$$

$$h = 2.32''$$

Case II: dynamic load

$$W = 2(\text{static load}) = 2(29.2) = 59.4\#/\text{in.}$$

$$M = \frac{59.4(72)^2}{8} = 37{,}800 \text{ in. }\#$$

$S = 8600$ psi Impact bending proportional limit for southern yellow pine. (See Table XXIII.)

$$8600 = \frac{37{,}800}{h^3}\frac{h}{2}\ ;\ h^2 = 2.2$$

$$h = 1.483$$

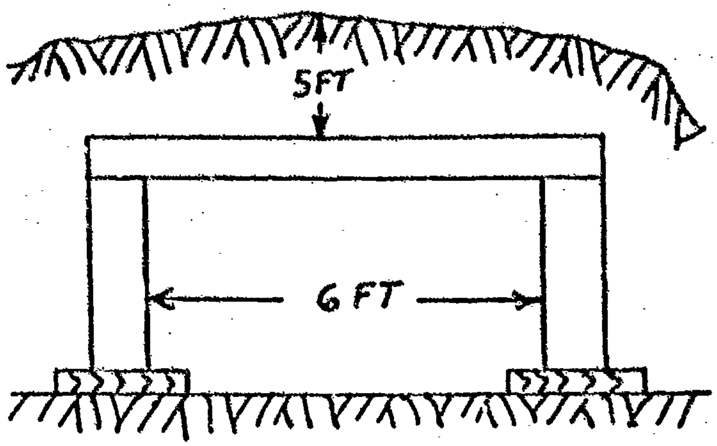
2.32" > 1.483

therefore, static load condition is critical.

So, specify lumber of standard size next above 2.32 inches thick; $2\frac{1}{2}$ inches rough or 3 inches finished.

(2) Example Calculation of Roof Timbers for a Closed Structure.

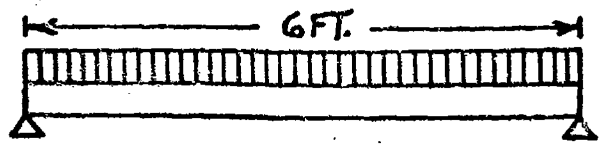
Given: A closed structure with a roof span of 6 ft. Radiation and other factors require cover of 5 ft of uncompacted, $70\#/ft^3$ soil. Overpressure reaches a maximum of 100 psi.



Problem: Design roof stringers.

Solution: For a closed structure, the dynamic load condition is usually critical, since no pressure waves can

enter the shelter. Consider a section of roof, 1 ft wide, and 6 ft long. Treat this as a simply supported, uniformly loaded beam.



Case I = Dynamic Load

w = load per inch of beam

$$= 100(12) + 2\,\frac{(5 \times 1 \times 70)}{12} = 1259.4 \text{ \#/in}$$

$S = \frac{Mc}{I}$ S = Impact bending proportional limit for southern yellow pine.

$M = \frac{wl^2}{8}$ M = maximum bending moment
c = beam thickness (h) ÷ 2

$= \frac{1259.4\,(72)^2}{8}$ I = moment of Inertia
l = length of beam

$= 815{,}000\text{"}\ \#$

S = 8600 Impact bending proportional limit for southern yellow pine.

$$8600 = \frac{815{,}000}{h^3}\;\frac{h}{2} \qquad h^2 = 47.4$$

$h = 6.88\text{"}$

Case II Static Load

$w = 5 \times 1 \times 70 \div 12 = 29.2$

$$M = \frac{(29.2)(72)^2}{8} = 18{,}900\text{"}\#$$

S = 1750 working stress for yellow pine

$$1750 = \frac{18{,}900}{h^3}\ \frac{h}{2} \qquad h^2 = \frac{18{,}900}{1750(2)}$$

$h = 2.32"$
$6.88" > 2.32"$
therefore dynamic load condition is critical.

So, specify lumber of standard size next above 6.88 inches thick; 7 inches rough or $7\frac{1}{4}$ inches finished.

Table XXIII. Practical Working Stresses for Certain Common Structural Materials**

Material	Design Working Stress (psi)	Impact Bending at Proportional Limit (psi)	Ultimate Stress (psi)
Wood:			
Douglas Fir (Coast)	2,000	9,800*	
Southern Yellow Pine	1,750	8,600	
Hemlock, Eastern	1,466	7,900	
Spruce (Sitka)	1,466	8,400	
Steel	20,000		50,000
Aluminum	11,000		25,000

* Note that wood can be stressed much higher under impact loads than under static loads.

** Wood Handbook, Washington: U. S. Forest Service, Department of Agriculture, June 1940.

For covered trenches, the cover support should be d signed as a simple beam although it actually would be a partly re strained beam. The beam should overlap the trench on each side a amount at least equal to the trench width. Widths of covered trenches should not be great, probably less than 6 ft. If the lo conditions or soil conditions are such that there is likely failu of the trench walls, then a method of transferring the load to th trench bottom is necessary. In this case, the post-cap-stringer combination is suitable. It is a good solution for the special t of shelter also since it readily adapts to a continuous design. This design also provides bracing for revetment.

c. Revetment. In most cases, the decision has to be made locally as to whether revetment is necessary or not. The ne for revetment depends on ground conditions and weapons effects. Facing revetment is preferable to the retaining-wall type since

requires less excavation and can usually be made stronger. Facing revetment has to be adequately braced, preferably at short distances, say 24 in. One-in. timber sheathing is satisfactory provided it is adequately braced. Many materials of lesser strength will be suitable in some cases. Chicken wire, with burlap or tarpaper, or metal sheeting are examples of suitable material. Bracing could consist of 2- by 4-in. timbers or metal pickets driven into the soil at the floor. It may be necessary in some cases to provide bracing for revetment across the width of the shelter at top and bottom. It is probably desirable, if feasible, to connect the revetment to the cover support. This will increase overall strength of the structure.

Transmission of blast pressures through soil is so little understood that no design theory can be stated for revetment. One source recommends that revetment be designed for 15 percent of the dynamic load on the cover support structure.

d. Entrances. The entrance is an extremely important part of a shelter. The design of blast-resistant doors is not a part of this report. However, in some situations, a blast door may be necessary. In this case, the door should be placed at the beginning of the entranceway so that it is subjected to sideon blast pressure only rather than reflected pressure which would occur if the door were deep within a long entranceway. One turn should be incorporated into the entranceway between the door and the shelter proper so as to eliminate the missile hazard if the door fails. If doors or curtains for CBR protection are installed, these could become missiles also. Test results have indicated that two 90-degree turns are necessary for protection against nuclear and thermal radiation.

If CBR curtains or doors are necessary, they should be installed in pairs, preferably with one turn between them to reduce the possibility of missiles perforating the protective material. Access to a shelter could consist of four different methods: vertical ladders, sloping ramps, stairways, and tunnels. The vertical ladder would be utilized with a horizontal tunnel-type entrance. The ramp-type entrance would be utilized by itself or in conjunction with a short horizontal tunnel-type section. Slope of the ramp should be no greater than 1 in 4. Stairway slope should be no greater than 2 in 3. A surface shelter would employ a horizontal tunnel-type entrance, while a deeply buried shelter would employ the ramp or long stairway-type entrance. A semi-buried shelter would probably employ the ladder or short stairway type in conjunction with a horizontal tunnel. Economics will probably govern, although ease of entry will be important. The ramp will permit the most rapid entry, while the ladder will be the slowest. Whatever the means of access, it should be almost entirely covered so as to restrict the entry of radiation to the beginning aperture only. Earth cover over

the entranceway is a decided benefit since it will reduce the entry of neutrons and gamma rays into the shelter proper. Since wind drag is so detrimental to entrances, it may be desirable to place the entrance aperture below ground level even for surface shelters if possible.

As much protection should be incorporated into the walls and roof of the entrance as in the revetment and cover support of the shelter proper. The essential difference between the two sections of the shelter would be cross-sectional area since the entrance would probably be quite smaller.

The dimensions of entrances depend on what will enter the shelter. One source gives minimum dimensions of width, 2 ft 6 in., and height, 5 ft 6 in. This will accommodate stretchers for rescue work. Another source states that an emergency exit should be capable of permitting the passing of one person by another. These dimensions seem acceptable although the size given for an emergency exit, a pipe of 3-ft diameter, could be acceptable for a main entrance if speed of entry is not essential. The important thing to remember is that for protection against nuclear weapons, the smaller the open entrances cross-section, the better the protection afforded. Small entrances may present a ventilation problem under extended occupation. Since length of an entrance will greatly affect total construction effort, length should be as short as possible consistent with necessary protection. The slopes of ramps and stairways may necessitate longer lengths.

The necessity of emergency exits is questionable. They were deemed necessary for protection against H. E. weapons in World War II, but whether they are necessary for nuclear warfare is in doubt. If they are similar to the main entrance, they will increase the intensity of many detrimental effects inside the shelter. A preferable design would be one similar to the type incorporated into the FCDA group shelter; i. e., a section of the cover support would be capable of being removed from the inside and the earth cover would fall into the shelter.

The plan of the entranceway can vary, although the usual plan will be roughly similar to a "Z." Orientation of the entrance can be extremely important. If a probable ground zero for a nuclear weapon is known, the beginning aperture of the entranceway should face away from it. Nuclear effects will probably be maximize inside the shelter if the entranceway faces the explosion.

e. Blast Walls. The value of this item is limited to H. E. weapons since other items accomplish the same purpose for nuclear shelters. In the present situation, it is apparent that this item should be eliminated.

f. Ventilation and Capacity. It is apparent that shelters should be designed for a practical maximum of 50 persons with a practical minimum of 10 sq ft of floor area per person. A minimum floor space per person is given as 6 sq ft for 12-hour occupation, while another source suggests 20 sq ft for two-week occupation. However, occupation duration will probably fall between the two extremes. For unventilated shelters, the most critical items will be surface area and interior volume. The apparent minimum surface area per person is 25 sq ft, while 100 sq ft is preferred. Surface shelters require more area per person than buried shelters. A shelter of equal dimensions, i. e., in the form of a cube, would require the greatest surface area per person while a long trench shelter would require the least area. The necessary surface area varies with duration of occupation, i. e., the longer the stay the greater the need for surface area. The data suggest that a surface area quantity of 100 sq ft per person be established for emergency shelters, except for a long trench shelter which would probably require no more than 50 sq ft. This would allow for extended occupation times. Protective curtains which will permit some exchange of air are desirable. Vents in the roof will also improve habitability of the shelter by providing some air exchange. Test results indicate that these devices will permit the entry of some nuclear effects but if properly designed will not admit them in dangerous amounts. The smaller the diameter of the vent, the lesser the entry of nuclear effects. Therefore, small diameter pipes, 6 in. or less, should be used in multiple rather than larger sizes in lesser quantity. In one instance, simple, 6-in. vents reduced the peak exterior overpressure of 21 psi to an initial peak of 11 psi and a maximum sustained pressure of 8 psi inside the shelter. Installation of blast closure valves in the vents is desirable. In this case, a larger diameter could be employed. Vents will admit neutrons and gamma rays and, to a lesser extent, thermal energy. Therefore, personnel should not be located directly below vents. Vents should incorporate a horizontal section at the top to prevent entry of fallout particles from above. These devices should be quite strong since many have failed under nuclear testing.

Under natural ventilation conditions, an air quantity of 6 cu ft per hour per person is considered necessary. The conditions of this quantity are that a roof vent be provided and that the door or closure device be occasionally opened for exchange of air. Data on ventilation contain some disparities. Dimensions are various shelter shapes and different totals of personnel are contained in Table XXIV.

In considering the several aspects of ventilation with due regard for factors such as number of personnel, shelter shape, expected occupancy time, climatic conditions, elevation of shelter, etc., the decision is not one which can be stated generally,

but with the various points before him, the shelter planner can reach his own solution.

Table XXIV. Shelter Space Requirements

No. of Per-sonnel	Floor Plan	Suggested Dimensions (ft) Width	Length	Height	Surface Area* Per Person (sq ft)	Volume Per Person (cu ft)
10	square	10	10	10	60	100
10	short rect.	5	25	6	61	75
10	long rect.	3	40	6	75	72
20	square	15	15	10	52	112
20	short rect.	10	20	7	41	70
20	long rect.	5	40	7	51	70
50	square	23	23	15	49	160
50	short rect.	10	50	9	41	90
50	long rect.	5	100	7	50	70

Notes: Minimum floor area, 10 sq ft per person.
Minimum volume, 65 cu ft per person.
Minimum surface area, for square plan, 50 sq ft per person; rectangular plan, 40 sq ft per person.

* Surface area is equal to total of areas of walls, floor and ceiling

g. Location. Location of the shelter can be critical. Certainly, it should not be subjected to debris loads from nearby structures. Low spots are ordinarily not desirable because of CBR effects and drainage problems although they are of value against prompt nuclear effects. Generally speaking, low spots should not be selected. Shelters should be placed for ease of construction and within access distance. Locations over underground utilities and subterranean construction must be avoided. Weather conditions have to be considered for defense against attacks. Stable soil condition are desirable.

Against prompt nuclear effects, maximum protection will be obtained if the shelter is oriented so that its main axis is perpendicular to the line of blast. If a probable ground zero is known, advantage can be taken of this fact.

h. Elevation. If soil conditions permit, the shelter should be placed below the ground surface for optimum protection. Chemical warfare presents the only increased effects hazard to buried shelters. Shelters should be placed on the surface only wher absolutely necessary. Economic conditions may require semi-buried shelters.

i. Radiation Attenuation Factors. The attenuation of nuclear radiation is a fairly definite item except for neutrons. Not enough data exist for accurate figures on neutron attenuation, Table XVI. Chemical composition of the soil cover is the governing factor in the attenuation of neutrons. Another pertinent thing to remember is that the attenuation of prompt gamma rays, Table XV, depends on slant thickness of earth cover while the attenuation of neutrons depends on minimum thickness. The attenuation figures given are for uniform field conditions; i. e., there are no side effects. However, these conditions will rarely exist. Earth cover 25 in. thick over a foxhole 4 ft deep would reduce prompt gamma by a factor of 10, but an open foxhole will reduce prompt gamma by a factor of 8 at the bottom; therefore, the correct attenuation factor for a foxhole with 25 in. of earth cover is 0.0125 rather than 0.1. For surface shelters, there would be essentially no side effects and the attenuation factors would be correct as given in Table XV. For buried or semi-buried shelters other than foxholes, attenuation will vary with depth and the top area. The attenuation provided by buried or semi-buried shelters is considerably greater than the depth of the earth cover over the compartment.

j. Fallout Shelters. Shelter for protection against fallout requires only that a sufficient amount of attenuating material be placed between personnel and the source of radiation to reduce it to a negligible amount. A semi-buried shelter represents the usual compromise between economy and protection. However, the value of placing a shelter below the surface must not be ignored. Overhead cover is of prime value during fallout. In a post-fallout situation, sufficient cover is required to attenuate radiation from particles directly overhead. The greatest hazard, however, exists at the ground surface. The best protection against this hazard is achieved by placing the shelter below ground - below the "plane of maximum radiation."

k. Construction. Savings of time and money can be realized by maximum utilization of mechanical equipment. Equipment can be used especially for excavations, placing backfill, and handling large shelter sections. A major part of the construction of emergency shelters will have to be done by hand. No attempt has been made to determine construction times and costs since they are subject to so many variables. Among these variables are materials, equipment, soil conditions, skill of personnel, etc.

l. Materials. In general, the desirable materials for emergency shelters should exhibit the following characteristics: strength, ductility, and resiliency in structural components and massiveness in the cover. Unreinforced masonry is not recommended as a structural element. Steel, timber, and concrete are desirable structural materials. Soil and rock are excellent cover materials. The important thing is to fully utilize available materials.

10. Shelter Types. An evaluation of the different shelter types and weapon effects against which each shelter type is effective is presented in the following subparagraphs:

a. Simple Shelters. The best types of simple shelter in terms of protection, time, material, and cost would be open and covered trenches. The foxhole is an improvement over the trench only in a tactical situation. As a shelter, it is only slightly more effective than a trench and requires considerably more effort per man. The open trench would be advantageous at a great distance from a probable ground zero. None of these is effective against chemical and biological attack.

The covered trench is definitely the most effective simple shelter. It can be closed fairly easily to provide additional protection against fallout and chemical and biological warfare. It has its limitations, particularly with respect to blast. Since the cover support rests on the sides of the trench, blast strength of the shelter will be limited by soil strength unless suitable revetment is provided. The interior dimensions of a covered trench are such that there is negligible attenuation of blast entering the shelter chamber. Results of nuclear tests indicate that this shelter should be limited to providing protection against maximum blast pressure of 20 psi and low neutron intensities.

b. Special Shelters. Test results indicate that the greater the depth of burial of a shelter the greater the protection afforded. For this reason, whenever maximum protection is desired, the buried shelter is preferred.

It is apparent that the surface shelter should be used only where ground conditions make it the only practical type. Such shelters are particularly vulnerable to atomic blast and nuclear radiation. Protection against drag force requires that the roof, walls, and floor be one continuous structure.

A long, large pipe section will provide an excellent buried shelter framework since it provides both lateral and vertical support. Entrance design will be greatly affected by depth of placement of the buried shelter. The buried shelter is the only one of practical design suitable for protection against high-intensity effects of nuclear weapons.

Where economy of time and material is important, the preferred design will usually be the semi-buried shelter. The necessary excavation for this shelter will furnish part and sometimes all of the needed earth cover. The shelter design will vary from a situation where only the earth cover projects above the ground surface to a situation where as much as 50 percent of the revetment projects

above the ground surface. In the design of semi-buried shelters, as test results indicate, continuity should be provided between revetment and cover support.

IV. CONCLUSIONS

11. Conclusions. It is concluded that:

a. Weapons effects data are available in sufficient detail for general design purposes subject to the limitations set forth in the following conclusions.

b. Acceptable limits for exposure of personnel to the various weapons effects remain to be established.

c. The design of cover support or framework is not a precise process because of insufficient data on the effect of earth cover on blast forces and insufficient data on the design of structures against dynamic loads.

d. The design of revetment is not a precise process because of insufficient data on the transmission of shock waves through soil.

e. Shelter entrances are quite vulnerable and therefore important. Their design merits careful attention.

f. There is a need for additional data on minimum essential ventilation required for shelters where extended stay times are involved.

g. Optimum protection is obtained when the shelter is placed wholly below the ground surface.

h. The attenuation of nuclear radiation, except for neutrons, is sufficiently understood for design purposes. Additional data are necessary before attenuation of neutrons can be accurately computed.

i. The design of shelters for fallout protection presents no problems except for the aforementioned need for additional ventilation data.

j. The covered trench shelter is the optimum type of shelter when costs, construction time, and protection are considered, provided soil conditions are not prohibitive.

k. When special shelter designs are necessary because of weapon effects or soil condition, the wholly or partially buried shelters are preferred.

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GLOSSARY OF TERMS

TERM	MEANING
Alpha Particle	A particle emitted spontaneously from the nuclei of some radioactive elements. It is identical with a helium nucleus, having a mass of four units and an electric charge of two positive units.
Attenuation Factor	The ratio of interior intensity of nuclear radiation to the exterior intensity. It is usually expressed as a decimal but occasionally as a fraction.
Beta Particle	A charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the fission fragments emit (negative) beta particles. Physically, the beta particle is identical with an electron moving at high velocity.
Blast Wave	A pressure pulse of air, accompanied by winds, propagated continuously from an explosion.
Critical Mass	The minimum mass of a fissionable material that will just maintain a fission chain reaction under precisely specified conditions, such as the nature and thickness of the tamper (or neutron reflector), the density (or compression), and the physical shape (or geometry). For an explosion to occur, the system must be supercritical, i.e., the mass of material must exceed the critical mass under the existing conditions.
Cube Root Law	A scaling law applicable to many blast phenomena. It relates the time and distance at which a given blast effect is observed to the cube root of the energy yield of the explosion.
Diffraction Loading	The force on a structure during the passage around and envelopment of the structure by the blast wave.

TERM	MEANING
Dose	A (total or accumulated) quantity of ionizing (or nuclear) radiation. The term dose is often used in the sense of the exposure dose, expressed in roentgens, which is a measure of the total amount of ionization that the quantity of radiation could produce in air.
Dose Rate	As a general rule, the amount of ionizing (or nuclear) radiation to which an individual would be exposed per unit of time. It is usually expressed as roentgens per hour or in multiples or submultiples of these units, such as milli-roentgens per hour. The dose rate is commonly used to indicate the level of radioactivity in a contaminated area.
Drag Loading	The force on an object or structure due to the transient winds accompanying the passage of a blast wave. The drag pressure is the product of the dynamic pressure and a coefficient which is dependent upon the shape (or geometry) of the structure or object.
Dynamic Pressure	The air pressure which results from the mass air flow (or wind) behind the shock front of a blast wave. It is equal to the product of half the density of the air through which the blast wave passes and the square of the particle (or wind) velocity in the wave as it impinges on the object or structure.
Dynamic Arching	The action of an earth cover by which the live load over a structure roof is diverted around the structure thru the surrounding soil, i. e., the soil over and around the roof forms an arch through the interaction of the soil particles. This would occur only when the depth of cover is equal to or greater than the roof span.
Elastic Range	The stress range in which a material will recover its original form when the force (or loading) is removed. Elastic

TERM	MEANING
	deformation refers to dimensional changes occurring within the elastic range.
Fallout	The process or phenomenon of the fall back to the earth's surface of particles contaminated with radioactive material from the atomic cloud. The term is also applied in a collective sense to the contaminated particulate matter itself.
Fission	The process whereby the nucleus of a particular heavy element splits into (generally) two nuclei of lighter elements, with the release of substantial amounts of energy. The most important fissionable materials are uranium-235 and plutonium-239.
Fusion	The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, namely, deuterium and tritium, combine to form the nucleus of a heavier element with the release of substantial amounts of energy.
Gamma Rays	Electromagnetic radiations of high energy originating in atomic nuclei and accompanying many nuclear reactions, e. g., fission, radioactivity, and neutron capture. Physically, gamma rays are identical with X-rays of high energy; the only essential difference is that the X-rays do not originate from atomic nuclei but are produced in other ways, e. g., by slowing down (fast) electrons of high energy.
Ground Zero	The point on the surface of land or water vertically below or above the center of a burst of a nuclear (or atomic) weapon; frequently abbreviated to GZ. For a burst over or under water, the term surface zero should preferably be used.
Half-Life	The time required for the activity of a given radioactive species to decrease to half of its initial value due to radioactive decay.

TERM	MEANING
Half-Value Layer Thickness	The thickness of a given material which will absorb half the gamma radiation incident upon it. This thickness depends on the nature of the material-it is roughly inversely proportional to its density- and also on the energy of the gamma rays.
Height of Burst	The height above the earth's surface at which a bomb is detonated in the air. The optimum height of burst for a particular target (or area) is that at which it is estimated a weapon of a specified energy yield will produce a certain desired effect over the maximum possible area.
Impulse	The product of the overpressure (or dynamic pressure) from the blast wave of an explosion and the time during which it acts at a given point. More specifically, it is the integral, with respect to time, of the overpressure (or dynamic pressure), the integration being between the time of arrival of the blast wave and that at which the overpressure (or dynamic pressure) returns to zero at the given point.
Ionizing Radiation	Electromagnetic radiation (gamma rays or X-rays) or particulate radiation (alpha particles, beta particles, neutrons, etc.) capable of producing ions, i. e., electrically charged particles, directly or indirectly in its passage through matter.
Kev, Thousand Electron Volts	A unit of energy commonly used in nuclear physics. It is equivalent to 1.6×10^{-3} ergs.
KT, Kiloton Energy	The energy of a nuclear (or atomic) explosion which is equivalent to that produced by the explosion of 1 kiloton (i. e., 1,000 tons) of TNT, i. e., 10^{12} calories or 4.2×10^{-19} ergs.
Lamination	The principle of building up a beam or roof in layers rather than using solid members. As used herein it does not refer to a true lamina because the individual layers are

TERM	MEANING
	spot fastened with nails rather than being glued.
LD-50, LD/50	Abbreviations for median lethal dose.
Loading	The force on an object or structure or element of a structure. The loading due to blast is equal to the net pressure in excess of the ambient value multiplied by the area of the loaded object, etc.
Median Lethal Dose	The amount of ionizing (or nuclear) radiation exposure over the whole body which it is expected would be fatal to 50 percent of a large group of living creatures or organisms. It is commonly (although not universally) accepted, at the present time, that a dose of about 450 roentgens, received over the whole body in the course of a few hours or less, is the median lethal dose for human beings.
MT, Megaton Energy	The energy of a nuclear (or atomic) explosion which is equivalent to 1,000,000 tons (or 1,000 kilotons) of TNT, i. e., 10^{15} calories or 4.2×10^{22} ergs.
Mev, Million Electron Volts	A unit of energy commonly used in nuclear physics. It is equivalent to 1.6×10^{-6} ergs. Approximately 200 Mev of energy are produced for every nucleus that undergoes fission.
Neutron	A neutral particle, i. e., with no electrical charge, of approximately unit mass, present in all atomic nuclei, except those of ordinary (or light) hydrogen. Neutrons are required to initiate the fission process, and large numbers of neutrons are produced by both fission and fusion reactions in nuclear (or atomic) explosions.
Nominal Atomic Bomb	A term, now becoming obsolete, formerly used to describe an atomic weapon with an energy release equivalent to 20 kilotons (i. e., 20,000 tons) of TNT. This was approximately the energy yield of the bombs

exploded over Japan and in the Bikini tests in 1946.

Nuclear Radiation — Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons standpoint, are alpha and beta particles, gamma rays, and neutrons.

Nuclear Weapon (or Bomb) — A general name given to any weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion or both. Thus, the A (or atomic) bomb and the H (or hydrogen) bomb are both nuclear weapons. It would be equally true to call them atomic weapons, since it is the energy of atomic nuclei that is involved in each case. However, it has become more or less customary, although it is not strictly accurate, to refer to weapons in which all the energy results from fission as A bombs or atomic bombs. In order to make a distinction, those weapons in which at least part of the energy results from thermonuclear (fusion) reactions among the isotopes of hydrogen have been called H bombs or hydrogen bombs.

Overpressure — The transient pressure, usually expressed in pounds per square inch, exceeding the ambient pressure, manifested in the shock (or blast) wave from an explosion. The variation of the overpressure with time depends on the energy yield of the explosion, the distance from the point of burst, and the medium in which the weapon is detonated. The peak overpressure is the maximum value of the overpressure at a given location and is generally experienced at the instant the shock (or blast) wave reaches that location.

Plastic Range — The stress range in which a material will not fail when subjected to the action of a force but will not recover completely, so that a permanent deformation results, when the force is removed. Plastic deformation refers to dimensional changes occurring within the plastic range.

TERM	MEANING
Prompt Nuclear Effects	The nuclear effects, e. g., neutrons, gamma rays, blast wave, alpha and beta particles, which occur within a few seconds or minutes after a detonation.
RAD	A unit of absorbed dose of radiation; it represents the absorption of 100 ergs. of nuclear (or ionizing) radiation per gram of the absorbing material or tissue.
Radiological Shelter	A shelter designed primarily for protection against nuclear radiation.
RBE (or Relative Biological Effectiveness)	The ratio of the number of rads of gamma radiation of a certain energy which will produce a specified biological effect to the number of rads of another radiation required to produce the same effect is the RBE of this latter radiation.
REM	A unit of biological dose of radiation; the name is derived from the initial letters of the term "roentgen equivalent man (or mammal)." The number of rems of radiation is equal to the number of rads absorbed multiplied by the RBE of the given radiation (for a specified effect).
REP	A unit of absorbed dose of radiation; the name is derived from the initial letters of the term "roentgen equivalent physical." Basically, the rep is intended to express the amount of energy absorbed per gram of soft tissue as a result of exposure to 1 roentgen of gamma (or X) radiation. This is estimated to be about 97 ergs, although the actual value depends on certain experimental data which are not precisely known. The rep is thus defined, in general, as the dose of any ionizing radiation which results in the absorption of 97 ergs of energy per gram of soft tissue. For soft tissue, the rep and the rad are essentially the same.
Roentgen, r	A unit of exposure dose of gamma (or X) radiation. It is defined precisely as the quantity of gamma (X) radiation such that

the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign. From the accepted value for the energy lost by an electron in producing a positive-negative ion pair in air, it is estimated that 1 roentgen of gamma (or X) radiation, would result in the absorption of 87 ergs of energy per gram of air.

Scaling Law — A mathematical relationship which permits the effects of a nuclear (or atomic) explosion of given energy yield to be determined as a function of distance from the explosion (or from ground zero), provided the corresponding effect is known as a function of distance for a reference explosion, e. g., of 1-kiloton energy yield.

Scattering — The diversion of radiation, either thermal or nuclear, from its original path as a result of interactions (or collisions) with atoms, molecules, or larger particles in the atmosphere or other medium between the source of the radiations, e. g., a nuclear (or atomic) explosion, and a point at some distance away. As a result of scattering, radiations (especially gamma rays and neutrons) will be received at such a point from many directions instead of only from the direction of the source.

Shielding — Any material or obstruction which absorbs radiation and thus tends to protect personnel or materials from the effects of a nuclear (or atomic) explosion. A moderately thick layer of any opaque material will provide satisfactory shielding from thermal radiation, but a considerable thickness of material of high density may be needed for nuclear radiation shielding.

Shock Front (or Pressure Front) — The fairly sharp boundary between the pressure disturbance created by an explosion (in air, water, or earth) and the ambient atmosphere, water, or earth, respectively. It constitutes the front of the shock (or blast) wave.

TERM	MEANING
Shock Wave	A continuously propagated pressure pulse (or wave) in the surrounding medium which may be air, water, or earth, initiated by the expansion of the hot gases produced in an explosion. A shock wave in air is generally referred to as a blast wave, because it is similar to (and is accompanied by) strong, but transient, winds. The duration of a shock (or blast) wave is distinguished by two phases. First, there is the positive (or compression) phase during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. In the second phase, the negative (or suction) phase, the pressure falls below ambient and then returns to the ambient value. The duration of the negative phase is approximately constant throughout the blast wave history and may be several times the duration of the positive phase. Deviations from the ambient pressure during the negative phase are never large and they decrease with increasing distance from the explosion.
Simple Shelters	These are readily constructed with a limited amount of effort and expenditure of materials. Some examples are prone shelters, foxholes, open and covered trench.
Slant Range	The distance from a given location, usually on the earth's surface, to the point at which the explosion occurred.
Special Shelters	These furnish greater protection but require considerably more effort and expenditure of materials than the simple shelters. They are further defined by their relationship to the ground surface, i. e., surface shelters, semi-buried shelters, buried shelters.
Buried Shelters	These, including their cover, are entirely below the ground surface.

TERM	MEANING
Semi-buried Shelters	These project partly above and partly below the ground surface.
Surface Shelters	These are situated entirely above the ground surface.
Surface Burst	The explosion of a nuclear (or atomic) weapon at the surface of the land or water or at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the bomb is detonated actually on the surface is called a contact surface burst or a true surface burst.
Thermal Energy	The energy emitted from the ball of fire as thermal radiation. The total amount of thermal energy received per unit area at a specified distance from a nuclear (or atomic) explosion is generally expressed in terms of calories per square centimeter.
Thermal Radiation	Electromagnetic radiation emitted (in two pulses) from the ball of fire as a consequence of its very high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages (first pulse), when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum.
Typical Air Burst	The explosion of a nuclear weapon for which the height of burst is such as may be expected to cause maximum blast destruction in an average city.
Yield (or Energy Yield)	The total effective energy released in a nuclear (or atomic) explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion. The total energy yield is manifested as nuclear radiation, thermal radiation, and shock (and blast) energy, the actual distribution being dependent upon the medium in which the explosion occurs (primarily) and also upon the type of weapon and the time after detonation.

APPENDICES

APPENDIX A

AUTHORITY

RDB PROJECT CARD	TYPE OF REPORT: NEW PROJECT		REPORT CONTROL SYMBOL CSPRD-1
1. PROJECT TITLE: FIELD FORTIFICATIONS AND OBSTACLES (EAM-Short Title FLD FORT OBSTL)		2. SECURITY OF PROJECT: U / 4. CETC NO. 2158/252	3. PROJECT NO. 8-07-06-005 / 5. REPORT DATE 8 February 54
6. BASIC FIELD OR SUBJECT: Mines and Obstacles	7. SUB FIELD OR SUBJECT SUB GROUP: Land		7a. TECH. OBJ. LC-13
8. COGNIZANT AGENCY: Corps of Engineers	12. CONTRACTOR AND/OR LABORATORY: Engr Res & Div Laboratories, Fort Belvoir, Virginia		CONTRACT/W. O. NO.
9. DIRECTING AGENCY: Engr Res & Dev Div, TO, OCE			
10. REQUESTING AGENCY: Office, Chief of Engineers			
11. PARTICIPATING AND/OR COORDINATING AGENCIES: AFF(Tech Asst & Facilities)(C); Marine Corps(" " ")(C); Ord. Corps (" " ")(C); Navy Bu Ord (Tech Asst)(C)	13. RELATED PROJECTS: 8-07-06-002		17. EST. COMPLETION DATES: RES. Cont.; DEV. ?; TEST ?; OP. EVAL. ?
	14. DATE APPROVED: 2 April 1954 by OSUSA as amended.		18. FY. / FISCAL ESTIMATES: 54 — 65 M; 55 — 75 M
	15. PRIORITY: 1-C	16.	
19.			

20. REQUIREMENT AND/OR JUSTIFICATION: This project is expected to provide new or improved items of material, equipment, and techniques for increasing the efficiency and ease of handling and construction of field fortifications and obstacles, to facilitate the movement and defense of field forces in the theater of operation, assist in the attainment of their military objective, more adequately meet the threat of increased firepower and destructive potentialities of present weapons and modes of warfare, including atomic, and provide increased defense against massed infantry attacks. The improved or developed items will decrease losses of materiel and personnel, and warrants the assignment of a 1-C priority.

21.

a. Brief:

(1). Objective:

This project is expected to improve present types and develop new types of field fortifications and obstacles, as well as equipment that will assist in the construction and erection of such items, and to provide additional protection and security to field forces in the theater of operations.

(2) Military Characteristics:

(a) The new and/or improved techniques, materials, and equipment developed shall facilitate the accomplishment of tactical missions.

22. RDB	ER.	CR.	TE & P	1.	2.	3.

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RDB PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
FIELD FORTIFICATIONS AND OBSTACLES (EAM-Short Title FLD FORT OBSTL)	U	8-07-06-005
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All materials and equipment developed shall be of:

1. Optimum simplicity of design.
2. Minimum weight and dimensions feasible for specific use, and to facilitate transporting and handling.
3. Optimum stability necessary for specific usage.
4. Such design as to take maximum advantage of locally available materials.
5. Optimum safety for transporting, handling and use.

(b) All techniques shall:

1. Be based on the specific tactical requirements.
2. Be simple in concept and practical in execution.
3. Give paramount consideration to speed, performance, security and economy.

(c) Detail characteristics will vary, depending upon the specific end item (excepting item referenced in paragraph 21a(2)(d) herein) and will be furnished in accordance with paragraph 21b(2) herein. In the event of conflict between the preceding general military characteristics and those furnished under paragraph 21b(2) herein, the latter will be the governing factor.

(d) Specific Military Characteristics: Foxhole Excavation Charge

1. The device shall be capable of providing a hole four feet in diameter and three feet deep with near vertical walls in soils of various densities, using a maximum of six pounds of Ordnance Corps standard type explosives.
2. The device shall be of the one-shot type design, and shall produce the required foxhole within two minutes time.
3. The device shall be capable of withstanding direct hits by small arms ammunition without initiation of the explosive.
4. The device shall be capable of air transportability in Phase 1. Parachute delivery is desired in aerial resupply operations. No additional items and/or personnel will be required in the same aircraft load to achieve combat effectiveness. Sectionalization of the item not required for air transportability.
5. The device shall contain such safety features as to require positive manual effort by the user, to effect detonation.
6. The equipment shall have the inherent capability of acceptable performance within an air temperature range extending from +125° F, minimum exposure of 4 hours with full impact of solar radiation; 360 BTU/Ft Sq/Hr, to -40°F, minimum exposure of 3 days without benefit of solar radiation; and shall be capable of safe storage and transportation without permanent impairment of its capabilities from the effects of temperature, at temperatures from -80°F, for periods of at least three days duration, to +160°F, for periods as long as 4 hours per day with full impact of solar radiation, 360 BTU/Ft Sq/ Hr.

R&D PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
FIELD FORTIFICATIONS AND OBSTACLES (EAM-Short Title FLD FORT OBSTL)	U	8-07-06-005
	4. CETC NO. 2153/252	5. REPORT DATE 2 February 54

7. The device shall be capable of being used safely at short ranges, with under 15 yards desired.

b. Approach:

(1) Based on tactical assumptions efforts will be made to improve the characteristics of field fortifications to increase the efficiency and ease of their usage, i.e., in their transportation, handling and construction. Especial attention will be given to the use of prefabricated sections of stable and light material designed to facilitate transporting, handling and erecting. Development of obstacles will be based on (1) their independent use as a means to delay and embarrass the enemy and (2) as an auxiliary means of defense of field fortifications. Especial consideration will be given to the development of prefabricated sections of steel obstacles such as hedgehogs and barbed wire. The potentialities of flame as an obstacle will be fully investigated, as also will be obstacles against amphibious assault and obstacles against airborne assaults. Coordination with employment of mine warfare will be considered.

(2) The accomplishment of the mission of this project shall be effected through six (6) specific and successive phases:

1. Confirmation of requirements by the using agency (Army Field Forces).
2. Investigation and evaluation by the developing agency, to determine the merits of possible approaches towards the solution of confirmed requirements.
3. Preparation of specific military characteristics.
4. Approval of the military characteristics by the using agency (AFF).
5. Approval of the military characteristics by appropriate amendment and/or revision to this project through action of the Corps of Engineers Technical Committee.
6. Research and development in accordance with approved military characteristics.

c. Subtasks:

(1) Related Project 8-07-06-002 pertains to the development of adapters for anchoring U type pickets in hard or frozen ground to facilitate erection of barbed wire obstacles.

d. Other Information:

(1) Basic Research - Not applicable

(2) References:

(a) Field Fortifications Manual, FM 5-15.

(b) Obstacle Techniques Manual, FM 5-30.

(c) Various Engineer Technical Intelligence Reports of field expedients use by both friendly and enemy forces in Korea, relative to the field of Fortifications, and Obstacles.

(d) Item 1263, CETC Meeting #238, Closing Project No. 8-07-06-001.

DD PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
FIELD FORTIFICATIONS AND OBSTACLES (EAM-Short Title FLD FORT OBSTL)	U	8-07-06-005
	CETC NO. 2158/252	5. REPORT DATE: 2 February 54

(e) "Advance Questionnaire for New Field Fortifications Project" as prepared by the ERDL, file TECRD-ME (Suspense Date 20 May 1953), and extracts of letters received by the ERDL in reply to the questionnaire referenced in preceding subparagraphs, said extracts consisting of 21 pages with dates varying from 5 May 1952 to 15 August 1952 in which requirements are stated for items pertaining to the basic field of "Fortifications and Obstacles".

(3) Discussion:

(a) Agreements have been made with Army Field Forces and Marine Corps to furnish technical assistance and facilities when required. Also, the Ordnance Corps has agreed to furnish technical assistance on questions of firepower.

(b) Agencies interested in this project, in addition to the Corps of Engineers, with which liaison will be maintained and which will be furnished copies of reports on the project are, Navy Department, Army Field Forces, Marine Corps, Ordnance Corps.

ENGNF (8-07-06-105)   22 April 1955

SUBJECT: Integration of Navy Project NY 340-032 - AW Protective Shelters

TO: Commanding Officer
Engineer Research and Development Laboratories
Fort Belvoir, Virginia

1. References:

a. Letter from Office, Chief of Engineers to Commanding Officer, Engineer Research and Development Laboratories, file ENGNF (8-07-06-105), subject: Emergency Shelters - Suggested Joint Army-Navy Action, dated 22 December 1954, with inclosures.

b. 1st Indorsement from ERDL to OCE, file TECRD MO 8-07-06-105 (22 Dec 54), same subject, dated 17 January 1955.

c. RDB Project Card, Symbol DD R&D (A) 119 (3950), for Navy Project No. NY 340-032, AW Protective Shelters, dated 15 February 1955, classified CONFIDENTIAL (copy inclosed).

2. The correspondence referenced in paragraphs 1-a and -b above describes preliminary planning for integrating Navy requirements for AW protective shelters into the present Corps of Engineers program in field fortifications. Subsequent to that planning, this office was advised that funds had become available in the Bureau of Yards and Docks, Department of the Navy, which would permit immediate transfer to the Department of the Army of $30,000, in lieu of $15,000 during FY 1955 and $15,000 during FY 1956 as originally planned. Accordingly, funds furnished under Navy Appropriation No. 21-17X1319.011 in the amount of $30,000 were transferred to ERDL under Corps of Engineers Allotment No. 8-5199 on 19 April 1955.

3. It is requested that the Department of the Navy requirements for AW Protective Shelters described as Phase I in the inclosed project card be integrated into the work presently being conducted under Project No. 8-07-06-105, in accordance with the preliminary plan set forth in the correspondence referenced in paragraph 1-b above.

BY COMMAND OF MAJOR GENERAL STURGIS:

1 Incl.
Cy Proj Card
NY 340-032

/s/ William J. New
/t/ WILLIAM J. NEW
Acting Chief
Engr Res & Development Division

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APPENDIX B

BACKGROUND

ENGNF (8-07-06-105) 22 December 1954

SUBJECT: Emergency Shelters - Suggested Joint Army-Navy Action

TO: Commanding Officer
Engineer Research and Development Laboratories
Fort Belvoir, Virginia

1. References:

a. Copy of 1st Indorsement from OCE to Chief, Bureau of Yards and Docks, subject as above, 23 November 1954 (Inclosure 1).

b. Copy letter from Chief, Bureau of Yards and Docks, subject: "Project NY 340-032 - Emergency Shelters - Accomplishment by Integration into Army Research and Development in Field Fortifications," dated 9 December 1954 (Inclosure 2).

2. On 9 November 1954, a preliminary conference was held at OCE between representatives of the Navy Department and OCE (Engineer Research & Development Division) regarding the feasibility of an Army agency performing research for the Navy in the field of "Emergency Shelters". As a result of the discussion, an outline of the present program in Field Fortifications, along with a request for more specific information, was forwarded to the Navy Department (Inclosure 1).

3. By letter of 9 December 1954 (Inclosure 2), the Navy Department has given the available additional information, along with the expected availability of funds.

4. It is desired that the information contained in the two inclosures be reviewed and a proposal submitted to this office indicating:

a. Plan for integrating this additional work into the present program.

b. Utilization of funds from the Navy.

c. Any adverse effect on present program due to the additional work load.

d. Estimate as to what the Navy may expect for their investment and when they may expect it.

5. In view of the desire to utilize FY 55 funds, available from the Navy Department, it is requested that this office be advised as to when the above information may be expected and of any requirement for a further meeting with Navy Department representatives prior to the resolution of the problem.

BY COMMAND OF MAJOR GENERAL STURGIS:

2 Incls:
1. Cy 1st Ind to Ch, BuDocks, 23 Nov 54
2. Cy ltr fm BuDocks, 9 Dec 54

/s/ C. T. Newton
/t/ C. T. NEWTON
Colonel, Corps of Engineers
Chief, Engr Res & Development Div.

TECRD MO
8-07-06-105 (22 Dec 1954) 1st Ind
SUBJECT: Emergency Shelters - Suggested Joint Army-Navy Action

Engineer Research and Development Laboratories, Corps of Engineers, U. S. Army, Fort Belvoir, Virginia

17 Jan 1955

TO: Chief of Engineers, Department of the Army, Washington 25, D. C., ENGNF

1. Reference is made to a conference in the Office of the Chief, Field Engineering Branch, Engineer Research and Development Division, Office, Chief of Engineers, on 11 January 1955, attended by:

Mr. W. F. Woollard, Field Engineering Branch, Engineer Research and Development Division, OCE.
Lt. Col. F. D. McGinnis, Field Engineering Branch, ER&D Div., OCE.
Commander A. B. Chilton, Jr., Research Division, Bureau of Yards and Docks, Navy Department
Mr. J. W. Terrill, Passive Defense Branch, Bureau of Yards and Docks, Navy Department.
Mr. J. P. Roysdon, Engineer Research and Development Laboratories.
Mr. R. M. Flynn, Engineer Research and Development Laboratories.

2. The conference was called for the purpose of discussing requirements of shelters for the Navy, conditions under which they would be constructed, materials available for construction, and the relation of the requirements of the Navy to present work on field fortifications. It developed that whereas ERDL is now directing all efforts toward the development of fighting emplacements with plans to explore the subject of shelters in the future, the Navy Department is interested exclusively in shelters and desires that at least a token effort be started on this subject immediately. It was agreed by all present that the sum of $30,000.00 which the Navy Department proposed to contribute, would not be sufficient to support any specific experimentation, but that it could be used to mutual advantage in the current program on fortifications and that, with this money, work could be started this year and completed by the end of 1956 on collecting and compiling information pertinent to the design of shelters. It was agreed that such a study would cover only information which may now exist in scattered places and would not require the development of new information. On this basis it was judged that the only real difference between the desires of the Navy Department and the ERDL program was one of timing, and that the proposed study could be started immediately without seriously dislocating current

plans, Commander Chilton emphasized that the Navy Department was especially interested in factors related to defense against atomic weapons, particularly defense against the effects of radioactive "fall-out".

3. The information contained in the inclosures has been reviewed as requested and a proposal is submitted herein covering the four points listed in paragraph 4 of the basic letter.

a. Plan for integrating this additional work into the present program. The proposed study represents work that was scheduled for initiation in FY 56, but it will now be started immediately. The work will be a paper study only and consist of the investigation, compilation and analysis of currently available data that may have pertinent relation to the construction and use of personnel shelters. No actual construction, tests or new work, other than a paper study, will be undertaken. Much of the material to be included in the study will be drawn from the results of current experiments with fighting emplacements, but only where they may be directly applied to shelters for personnel protection. Consideration will be given to the various probable physical, operational and tactical conditions that might be encountered. The work that will be accomplished through this joint Army-Navy action will be generally essential to the field fortifications project and in any event would have been eventually undertaken under present project plans.

b. Utilization of Funds from the Navy. Funds will be utilized for salaries of personnel engaged directly in the proposed study, for the procurement of materials and supplies, and in payment for internal services in support of those portions of the experimental work on fighting emplacements which may produce information directly applicable to shelters.

c. Adverse effect on present program. By initiating the study on shelters this fiscal year, instead of next, it will be necessary either to defer planned work on the study of engineering materials for emplacements or to hire additional personnel so that both studies can be carried out at the same time. The decision as to which course to follow will be made locally.

d. Estimate as to what the Navy may expect for their investment and when they may expect it. A semi-annual letter report, plus a final letter report, will be submitted to the Navy. During the first six months of work, preliminary gathering of available data only will be accomplished. Thereafter, besides the continued gathering of data, its compilation in proper form and categories and its analysis will be undertaken. In the final compilation and presentation of the data, an effort will be made to have it in such a form that it will be readily useable in various tactical situations for

the construction of personnel shelters. It is expected that this study will be completed during 1956. It is emphasized that the work and accomplishments will be governed and limited by the understanding set out in this indorsement.

4. In consideration of the investigation to be performed by ERDL, the Navy Department will advance funds immediately in the amount of $15,000.00 for use in fiscal years 1955 and 1956, and when and if available will advance an additional sum of $15,000.00 in fiscal year 1956 for use in fiscal years 1956 and 57.

5. Form 1080, in the sum of $15,000.00, partially to cover work during fiscal year 1955 and 56, is inclosed herewith for submittal to the Navy Department.

FOR THE COMMANDING OFFICER:

3 Incls
1 - 2 n/c
Added 1 incl
3. Form 1080 (quin.)

/s/ C. P. Joyce, Jr.
/t/ C. P. JOYCE, JR.
Colonel, CE
Chief, Military Engineering Department

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Category 13 - Mine Warfare and Demolitions

DISTRIBUTION FOR USAERDL REPORT NO. 1554-TR

TITLE Emergency Personnel Shelters (U)

DATE OF REPORT 17 Nov 58 PROJECT 8-07-10-420 CLASSIFICATION Confid

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